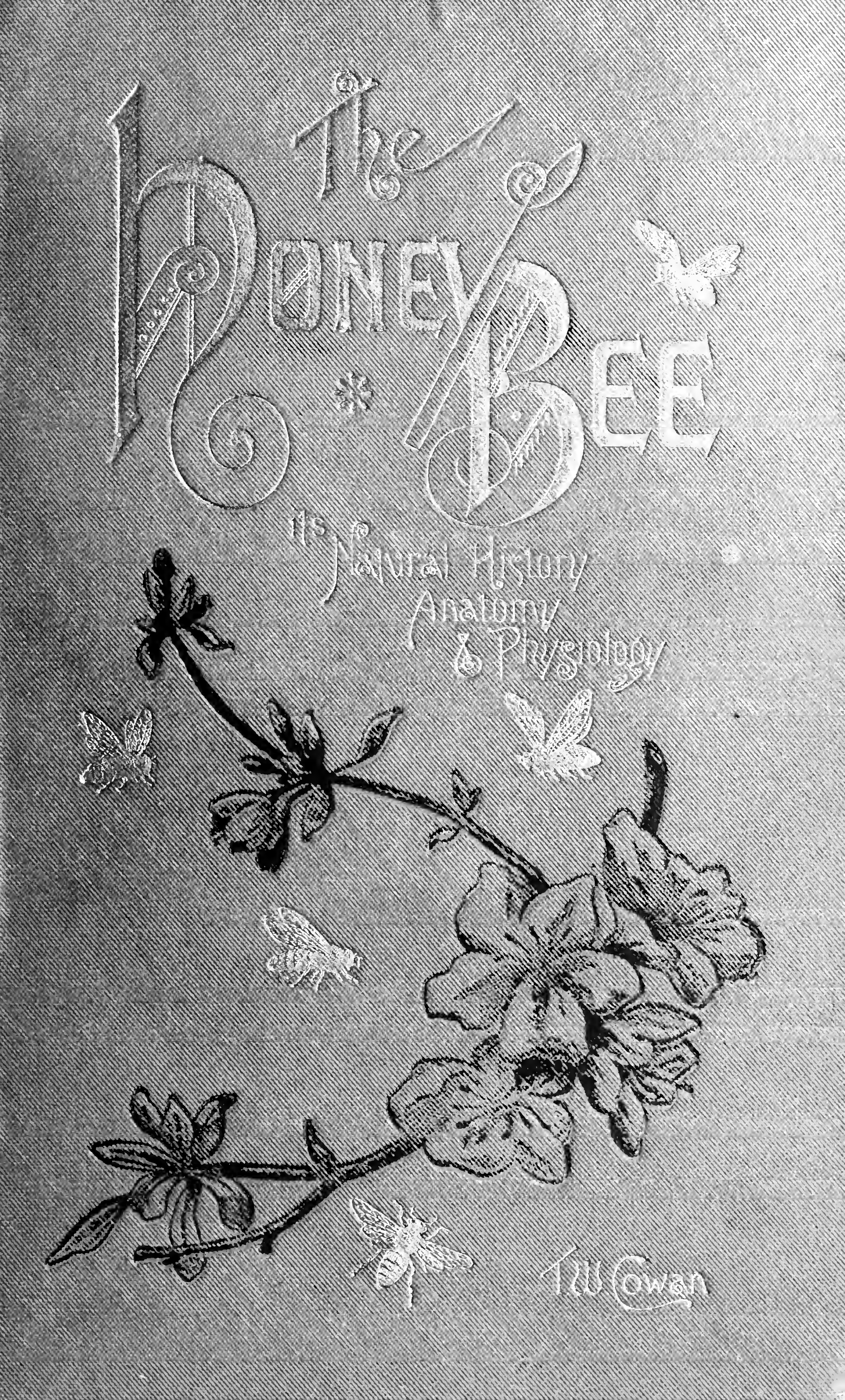
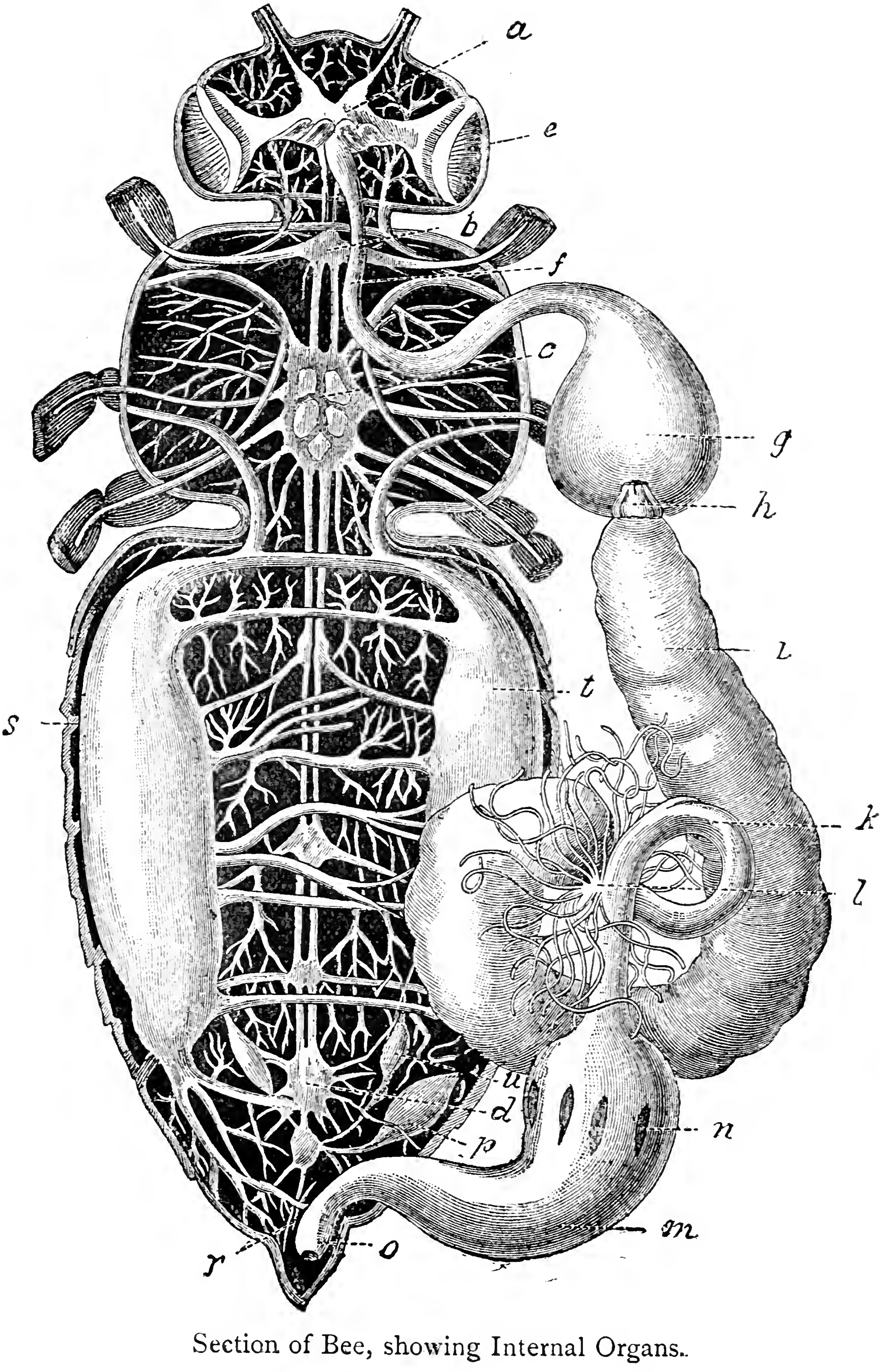

The Honey Bee
its Natural History
Anatomy
& Physiology
T. W. Cowan



Section of Bee, showing Internal Organs.

THE HONEY BEE:

ITS NATURAL HISTORY, ANATOMY, AND PHYSIOLOGY.

Thomas William

BY

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Illustrated with Seventy-two Figures of One hundred and thirty-six Illustrations.

C.

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PREFACE.

VERY few words of apology will be needed in bringing out another book on the honey bee. Already we have a host of classical writers, such as Swammerdam, Réaumur, Huber, and others who have written on the subject, works of marked excellence, and availing themselves of the improvements in general science in the last century, they made many interesting additions to our knowledge on the subject. Nevertheless, recent improvements in the microscope, and our constantly increasing knowledge, reveal new facts in addition to those already ascertained, frequently pointing to errors which longer experience and observation have enabled us to detect. As our stock of knowledge increases we find accepted theories fading away and giving place to others of a different character. During the present century much

has been done by such men as Siebold, Leydig, Schönfeld, Schiemenz, and others, to clear up difficult problems; but unfortunately the results of their works are not always accessible, as they are scattered throughout the proceedings of different Societies. They have never yet been collected into one volume. Frequently these works have appeared as monographs treating of some particular organ, and valuable as these are to the general entomologist, they contain an immense amount of matter of little use to the specialist. The exhaustive manner in which the subjects are generally treated makes them very expensive and out of reach of the average student. When an attempt at compilation is made, frequently discoveries are mentioned without alluding to the names of the discoverers, and the student is at a loss to know to whom the discoveries are due, they being often erroneously attributed to the writers of these compilations. Many such books contain a large amount of superfluous matter, tending to increase the size and cost without adding to the value, and frequently theories long since abandoned are discussed merely for the purpose of refuting them, thus swelling the size of the volume.

Having been engaged for many years in micro-

scopical investigation, more especially in connexion with the anatomy of the honey bee, we have been repeatedly urged by friends to supply a long-felt want of a book that could be used by the student as a text-book on the subject. In complying with this request our object has been to supply this want of a work which would embody in a compact form all the recent discoveries found scattered in various periodicals and proceedings of Societies. Whilst treating the subject in a thorough and exhaustive manner, it is written in the same concise style as the *British Bee-keeper's Guide-book*, which has already been so favourably received that nineteen thousand copies have been circulated. This work is divested of all verbiage, superfluities, and exploded theories. Although some of our matter is new, the greater part is an exposition of the discoveries in the subject up to the present time. Great care has been taken not to consider as established facts any discoveries that have not been again and again verified by experiments. Except in the case of facts long ago established, we have deemed it right to give the names of discoverers and authors to facilitate study, and at the end of this book are given the names of some of the works consulted and

referred to in the text. Most of the discoveries alluded to have undergone a careful microscopical examination.

Accurate figures add very much to the value of a work of this sort; we have therefore drawn, with the few exceptions mentioned below, the anatomical and physiological illustrations either direct from the objects themselves, from our microscopical preparations, or from photo-micrographs taken by us specially for this purpose. These illustrations are figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, 18, 19, 22, 28, 30, 31, 34, 36, 41, 50, 52, 53, 57, 58, 62, 63, 64, 66, 67, 68, 69, 70, 71, 72. The following illustrations are copied from—Witzgall, frontispiece; Hicks, 11; Kraepelin, 12; Wolff, 13, 14, 21, 23, 39, 40, 43, 51; Marey, 20; Macloskie, 24; Claus, 25; Girard, 26, 27, 53; Brandt, 29; Dujardin, 31, 32; Hyatt, 35; Krancher, 37; Schiemenz, 38, 47, 48, 49, 59; Lowne, 44; Grenacher, 45, 46; Leuckart, 54; Gravenhorst, 61, 65; Vogel, 56; Lucas, 60. We have also introduced a few diagrams to illustrate more clearly the functions of different parts. Where there is any confusion in the nomenclature of the different terms we have adopted Kirby's terms.

For easy reference all the illustrations have been described at pages 193–199.

Much time has been spent to make this book as concise as possible, to bring it within reasonable limits, and although no pains nor expense have been spared to make it the most perfect work of its kind, it is issued at a price that will bring it within the reach of every one.

We hope that it will prove useful, and be found to form an indispensable work of reference to the student as well as to the practical bee-keeper, to whom a knowledge of the natural history and habits of the honey bee must be of assistance in his practical work.

THOS. WM. COWAN.

31 *Belsize Park Gardens,*
Hampstead, N.W., November 1890.

Note.—The figures between brackets in the text refer to the works on pages 200–208.

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THE HONEY BEE.

CHAPTER I.

THE HIVE BEE.

The Honey Bee's Position in the Animal Kingdom—Classification —Annulosa—Arthropoda—Insecta—Hymenoptera—Apidæ —Apis Mellifica.

WHEN we endeavour to classify objects in nature, we separate them into three great divisions, which are known as the Animal, Vegetable, and Mineral Kingdoms.

These are again divided into groups, and in one of the principal sections of the *Animal* kingdom is the sub-kingdom *Annulosa*, so called from the animals included in it having bodies arranged in rings, or *articulata*, because they are composed of a number of joints or segments joined or articulated to each other. This is again separated into two divisions: those not having jointed feet, and *Arthropoda*, or those with jointed feet. Amongst these we find insects and crustacea, such as lobsters or crayfish.

The Arthropoda are therefore split up into classes, and now we find our bee in the class *Insecta*, or insects.

This class differs from the others in many important characteristics. Insects are provided with one pair of antennæ, and six legs only when in the perfect state. Their body is separated into three distinct divisions, viz., the head, thorax, and abdomen; and they pass through four stages of existence, called respectively egg, larva, pupa, and imago.

By a further sub-division into orders we find our insect belongs to the order of *Hymenoptera* (Gr. *humen*, a membrane; *pteron*, a wing). They are characterised by possessing four membranous wings, of which the anterior, or front pair, are the larger of the two.

Of all orders into which insects are separated, that of the Hymenoptera contains the largest number remarkable for development of instinctive powers and social qualities. Amongst these we find, in company with our bees, ants, wasps, ichneumons, and others.

These are, therefore, again separated into families, and here, amongst the *Apidæ*, which feed their young entirely on pollen, or honey and pollen, we find, besides the honey bee, the humble, carpenter, mason, and other bees. This family is yet further subdivided into genera, of which there are nineteen, and here we find our bee belonging to the genus *Apis*, in which we find several species—only one, *Mellifica*, being indigenous to Great Britain.

Class			INSECTA.		
Orders	Diptera. (Flies, &c.)	Lepidoptera. (Butterflies, &c.)	**Hymenoptera.** (Bees, Wasps, Ants, &c.)		&c.
Families ...	Vespidæ. (Wasps, &c.)	**Apidæ.** (Bees, &c.)	Crabronidæ. (Sandwasps, &c.)	&c.	&c.
Genera	Bombus. (Humble Bee.)	Xylocopa. (Carpenter Bee.)	**Apis.** (Bees.)	&c.	&c.
Species	**Mellifica.**	Fasciata.	Dorsata.	&c.	&c.
Varieties ...	English.	Cyprian.	Italian.	Carniolan.	&c.

CHAPTER II.

THE BEE NATION.

Economy of the Hive—Active Life of Community—Combs—Worker Bees—Pollen—Honey—Queens—Drones—Fertile Workers—Larvæ and Pupæ—Brood Feeding—Moulting of Skin and Bowel—Cocoon Spinning—Transformations—Swarming.

BEFORE we enter into a minute investigation of the anatomy and physiology of the honey bee, it will be well for us to get a general idea of the economy of the hive, and for this purpose we will select a prosperous colony at the commencement of the swarming season, in a movable comb hive, when it usually consists of a fertile queen, drones, and workers.

If we stand outside such a hive, we shall see the workers, who represent the active life of the community, leaving and entering it.

Victor Rendu (142) has given an admirable description of the scene we are witnessing. He says:—

'The exterior of a hive gives the best idea of this people, essentially laborious. From sunrise to sunset, all is movement, diligence, bustle; it is an incessant series of goings and comings, of various operations which begin, continue, and end, to be recommenced. Hundreds of bees arrive from the fields, laden with materials and provisions; others cross them and go in their turn into the country. Here, cautious sentinels scrutinise every

fresh arrival; there, purveyors, in a hurry to be back at work again, stop at the entrance of the hive, where other bees unload them of their burdens; elsewhere it is a working bee which engages in a hand-to-hand encounter with a rash stranger; further on the surveyors of the hive clear it of everything which might interfere with the traffic or be prejudicial to health; at another point workers are occupied in drawing out the dead body of one of their companions; all the outlets are besieged by a crowd of bees coming in and going out—the doors hardly suffice for this hurrying, busy multitude. All appears disorder and confusion at the approaches to the hive, but this tumult is only so in appearance; an admirable order presides over this emulation in their work, which is the distinctive feature in bees.'

Now, if we open our hive by removing the top, we shall find rows of frames, each filled with a comb hanging from its top bar, and fixed to those at the sides. These frames are usually placed so that they hang $1\frac{9}{20}$ths of an inch from centre to centre. On lifting one out, we shall find that the comb is made up of innumerable, usually six-sided, cells of different sizes. Fig. 1 shows in a small compass the different sizes and forms of cells.

Most of the cells are $\frac{1}{5}$th of an inch wide in their narrowest diameters—that is, between the parallel sides. These are called worker cells, and the combs are composed of two layers of such cells placed back to back, and lying nearly horizontally, arranged in such a way that the bases of the one become the bases of the other, the base of each little cell being formed by the union of the bases of three opposite cells.

Such comb is called worker comb, and the thickness, from the openings of the cells on one side to those on the other, is about $\frac{7}{8}$ths of an inch. There will

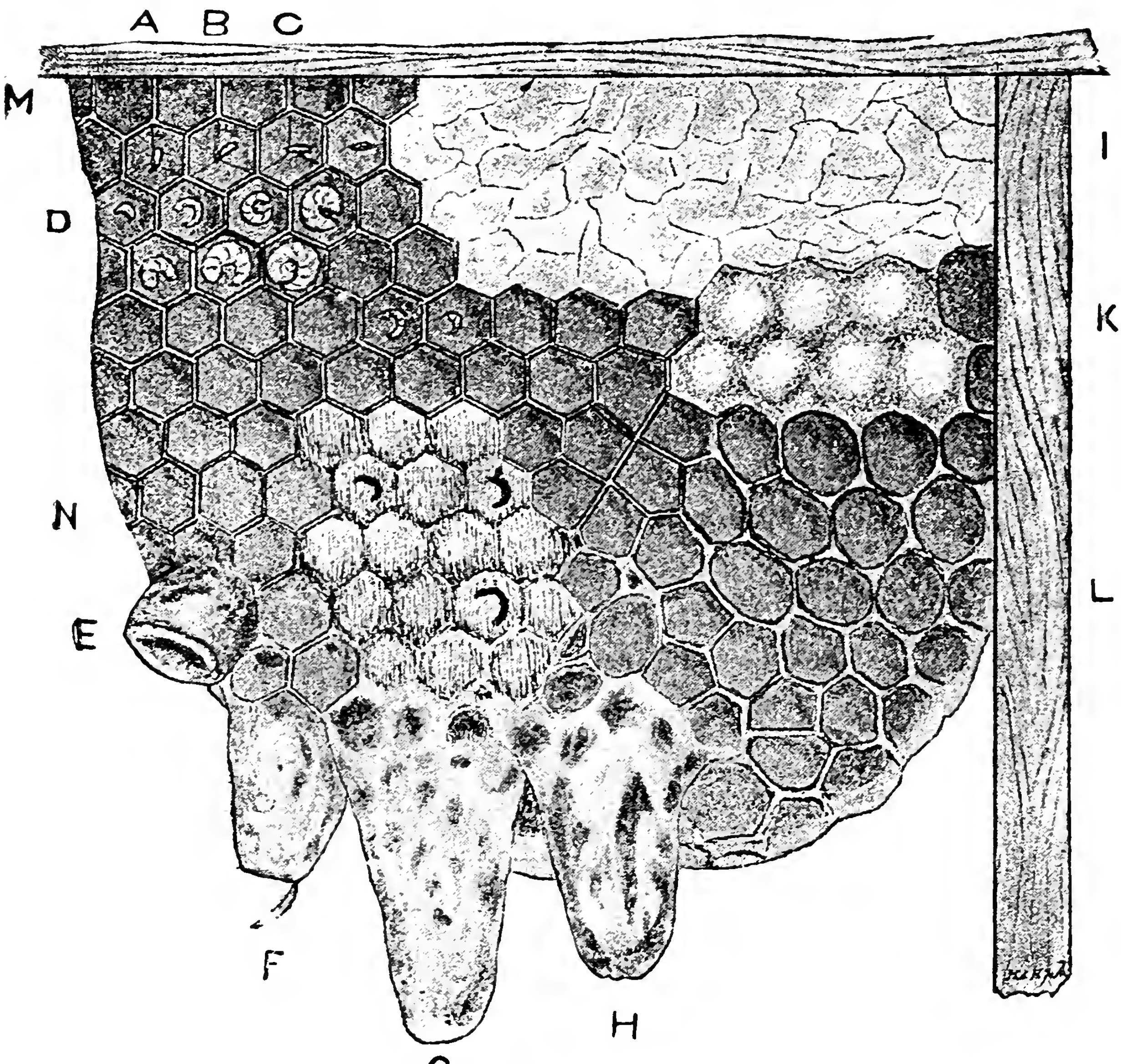


Fig. 1.

also be found larger cells, $\frac{1}{4}$ of an inch in diameter, called drone cells (K, Fig. 1), and others of peculiar shape (F, G, H, Fig. 1), instead of being placed horizontally, hanging with their openings downwards ;

these are queen cells. There may be others of irregular shape and size, sometimes five and seven-sided (L, Fig. 1); these are called transition cells, and are constructed for the purpose of passing gradually from worker to drone cells, or *vice versâ*. Then we shall also find along the top (M, Fig. 1) and sides, where the comb is fixed to the wood, cells having four and sometimes five sides; these are called by German bee-keepers attachment cells (*Heftzellen*).

Bees engaged in different occupations will be found on these combs; some fresh from the fields discharging their loads of pollen and honey, others engaged in feeding the young, whilst others will be capping over cells or comb-building. If we watch a bee just from the fields, we shall probably see her remove the pollen (which is the fertilising dust collected from flowers) from her legs, and place it in one of the smaller-sized cells which usually serve for this purpose; then putting her head in she presses it down firmly. She then goes to another cell and discharges into it from her honey stomach the liquid she has collected, but not before the nectar which was gathered from the flowers has been converted into honey by a secretion derived from the salivary glands. Both honey and pollen are used as food by the bee, and form the primary substance from which the brood food is derived. Water is also used, but is not stored, and the bees only collect it as required.

Of the three kinds of bees, the queen (Fig. 2), or as she is more correctly called by the Germans, the

mother bee, is a fully developed female, and is the only one capable of laying eggs which produce all the inhabitants of the hive. Dzierzon (37) propounded the theory that eggs in the ovary of the queen were all alike, but before laying those which could produce females she must mate with a drone; and Leuckart (93) and Siebold (153) proved that eggs destined to produce females were impregnated by introducing into them a fertilising substance originally derived from the drone, and for controlling the flow of which they found special voluntary muscles. Eggs laid without the addition of this fertilising substance produce only drones. The fertilisation of the queen once accomplished suffices for her life.

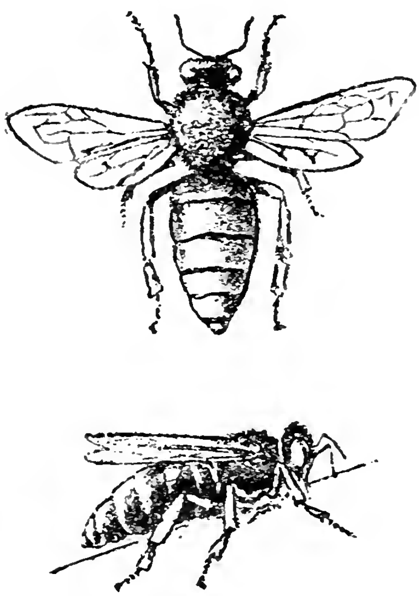


Fig. 2.—Queen.

The object of the drones (Fig. 3), of which there may be several hundred in a hive, is to impregnate the queen, therefore they are usually found in the hive only during the summer months, when their services may be needed. They are much more bulky than the queen

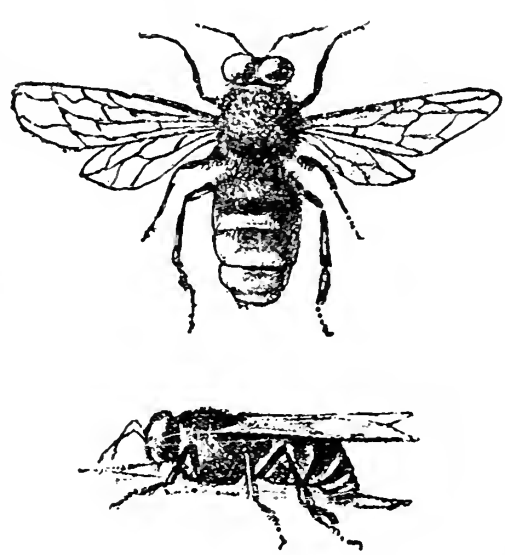


Fig. 3.—Drone.

and are larger than the workers, have no stings, and lead an idle life. At the end of the season, when their services are no longer needed, they are driven out of the hive and are allowed to perish.

The workers (Fig. 4) are undeveloped females, the most numerous in the colony, and smaller than either queen or drones. On them devolves all the work of the hive. The younger ones do the indoor work, act as nurses, feed the grubs, queen, and drones, and as they grow older go out collecting.

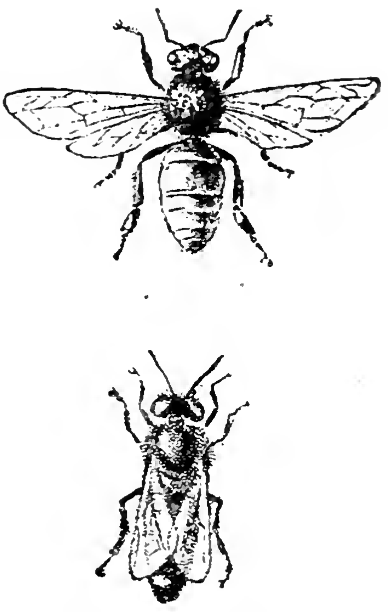


Fig 4.—Worker.

Sometimes, in the absence of a queen, workers will be found to lay eggs; but as they are not capable of mating with a drone the eggs they produce are not fertilised, and from them only drones proceed.

Now, let us watch the queen, and carefully follow the various stages through which a bee passes from the egg to the mature insect.

We shall see the queen moving slowly over the combs surrounded by a number of workers, which are constantly touching her with their antennæ and offering her food. She stops at an empty cell, examines it by putting her head inside, then, hanging on to the edges of the comb, inserts her abdomen, and deposits at the base of the cell, to which it is attached by a glutinous secretion, a little bluish-white oblong egg. She then proceeds to other cells and

repeats the operation in the same way. It will be noticed that the egg (Fig. 1, A) stands in a position parallel to the sides of the cell, and this position it retains the first day. On the second day it is inclined at an angle of about 45 degrees (Fig. 1, B), and on the third day it assumes a horizontal position (Fig. 1, C), resting perfectly flat on the base of the cell. The egg contains a vital germ, which, kept at a suitable temperature and fed by the egg substance within, develops into a tiny white grub on the fourth day, which is then supplied with a pap (*bouillie*) by the nurses as soon as it leaves the egg. Sometimes the hatching of the egg is retarded for a day or even more, especially if the temperature be low.

This brood food is prepared by the young workers only, and was supposed by Schiemenz (144) and others to consist entirely of a secretion produced by glands; but Schönfeld (147) has shown that although a secretion from the glands may be added, the food was really elaborated in the chyle stomach of the bee. Dr. A. de Planta (133) has abundantly proved this by his elaborate chemical experiments on the food given to the different larvæ, and showed that it varied in quality for the different sorts of bees, as well as in the quantity supplied. This, called *chyle food* by Dzierzon (38) and *pap* by Berlepsch (3), is supplied for three days to a worker, and then Leuckart (93) discovered that weaning took place, stating that honey and pollen were added until the larvæ are full grown. Dr. de Planta (133), however, found that although weaning took place as

stated by Leuckart, honey and *digested pollen* from the chyle stomach were given in the form of *chyle.* The larva partially floats in this pap, which is white and at first insipid, and being able to reach the food with very little movement it grows rapidly. It also, besides taking it through its mouth, absorbs it through that part of the skin in contact with the food. The illustration (Fig 1, D) shows the development of the larva in the five days it is attaining its full growth. During this time, Newport and Vogel (166) have shown that it casts its skin, like all other insects, several times. Newport (121) says:—

'But it is not merely the external covering which is thrown off during these changes; the whole internal lining of the alimentary canal also comes away with the skin, as was formerly noticed by Swammerdam, and repeatedly observed by ourselves and others. The lining of the mouth and gullet, and that of the mandibles, is detached with the covering of the head, and that of the larger intestines with the skin of the posterior part of the body; and besides these, the lining of the tracheal tubes comes away. The lining of the stomach itself, or that portion of the alimentary canal which extends from the termination of the œsophagus to the insertion of the so-called biliary vessels, is also detached, and becomes completely disintegrated, and appears to constitute part of the mass voided by the insect on assuming the imago state.'

This has been corroborated by Bonnet, Burmeister (17) and others, although recently given out as a new discovery. Before the last moult the cell is sealed over with a porous convex capping (Fig. 1, N),

proved by Dr. de Planta (129) to consist of wax and pollen, and the larva spins a cocoon, the threads of which are produced by a fluid (secreted by a gland) which flows from an opening in the lip and hardens into a thread. It then for a last time casts its skin as already explained, together with the lining and contents of the stomach. It is now called pupa, chrysalis, or nymph. The skin during this last moult adheres to the sides of the cell and the cocoon is joined to it. Dr. de Planta found the silk fibres also in places attached to the under side of the cell covering, and he says this porosity of cappings (to which we have alluded above) is of physiological importance for the vital functions of the larva, and says further that it is not astonishing that this porosity is more pronounced even in the sides of queen cells, in which such a precious creature as a queen bee has to breathe.

As the larva decreases in length, the cappings with the silk fibres can be removed for examination without touching the head of the chrysalis. During its imprisonment the larva derives air through the minute openings in the caps of the cells.

Marvellous transformations now take place, which will be more fully described in a future chapter. In about twenty-one days from the laying of the egg, the various transformations having been completed, at the last moment, Girard (48) says, the insect rolls off the thin pellicle which surrounds the pupa, and with its feet pushes it down into a pellet the size of a pin's head to the bottom of the cell. At last the perfect worker bites round the roof of the cell (Fig. 1, N) which

held her captive, and then forces her way out, a weak and silvery-grey young bee, the moist hairs adhering to her. In about twenty-four hours she will be ready to commence work in the hive as a nurse, and it is not until ten or twelve days afterwards that she will be able to fly out and collect food for the support of others. As soon as a bee leaves a cell, this is cleaned out by others, and numbers of them will be seen constantly examining the cells with their antennæ.

The queens are reared in large cells of peculiar shape (Fig. 1, F, G, H), whose sides as well as cappings are porous (Planta, 129) and consist of wax and pollen. They are produced from eggs fertilised in the same way as those of workers, and the difference in the development of the insect is caused by the peculiar kind and great abundance of rich food administered to the larva, which literally floats in it, and it being, as Leuckart (93) and Planta have shown, fed with the same kind of food during the whole of its larval existence, instead of being weaned like the workers and drones. This has the effect of fully developing her ovaries, and she leaves the cell, in about fifteen days from the day the egg is laid, as a female capable of reproducing the species.

The drones, as we have said, are produced from unimpregnated eggs, and take about twenty-four days from the laying of the egg to reach maturity. They are weaned by having honey and undigested pollen added to their food after the third day. The cappings of their cells (Fig. 1, K) are more convex than those of the workers, but are also porous.

The honey cells (Fig. 1, 1) are capped by flatter air-tight coverings of wax, either white or various shades of yellow, the colouring, as we shall see later, being derived from the pollen.

As the queen is able to lay from 2000 to 3000 eggs a-day, when hatching has begun each day adds large numbers of young bees to the population of the hive, which is not long in becoming too small for the number of its inhabitants. It is then that, unless measures are taken to prevent it, swarming takes places. The queen leaves the hive with a portion of the inhabitants and founds a new colony elsewhere. When the emigration is effected, a queen hatching out of one of the queen cells takes the place of the old one, and, after mating with a drone, becomes for the time being the mother of the colony.

Having settled in a new hive, the bees commence by stopping up all superfluous openings by means of propolis, a resinous substance collected principally from the buds of plants, and brought home on their hind legs. They have also to furnish their new home with combs made of wax, which is secreted by glands in the bodies of the workers. These combs are in turn occupied by brood, the same work which we have described is continued, and the swarm, if properly managed by the bee-keeper, soon grows into a strong colony, called a stock. Having given an outline of the internal economy of a hive, we shall in future chapters dissect our bees and study them anatomically.

CHAPTER III.

EXTERNAL SKELETON.

Structure—Chitine—Hypodermis and Epidermis—Hairs and their Uses—Hairless Bees—Division into Three Parts.

THE honey bee, like all other insects, has neither bones nor cartilaginous framework. The external covering is formed of a tough and leathery skin, which looks like horn, but is very different from it in its composition. This substance is called chitine. It is not acted upon by ordinary solvents, such as water, alcohol, ether, or diluted acids, and differs from horn, which dissolves readily in a weak solution of potash.

The thick and the thin outer skins, whether they form the rings, wings, hairs, eyes, or joints which are pliable and easily folded, are composed of this same substance. The skin is formed of two layers—an inner one, called the *hypodermis*, or true skin, soft and not made up of chitine; and the outer one, called *epidermis*, composed of chitine, to which are added, according to the stages of development of the insect, more or less colouring matter, fat, and calcareous salts. It is this outer skin which is detached and cast during the progress of development, and not only forms the hard external skeleton, but also the internal braces, tendons, and membranes.

Every part of the epidermis is covered more or

less with hairs (Fig. 5), and many of them spring from bulbs or roots connected with nerves. These hairs are composed of chitine, and in this respect they

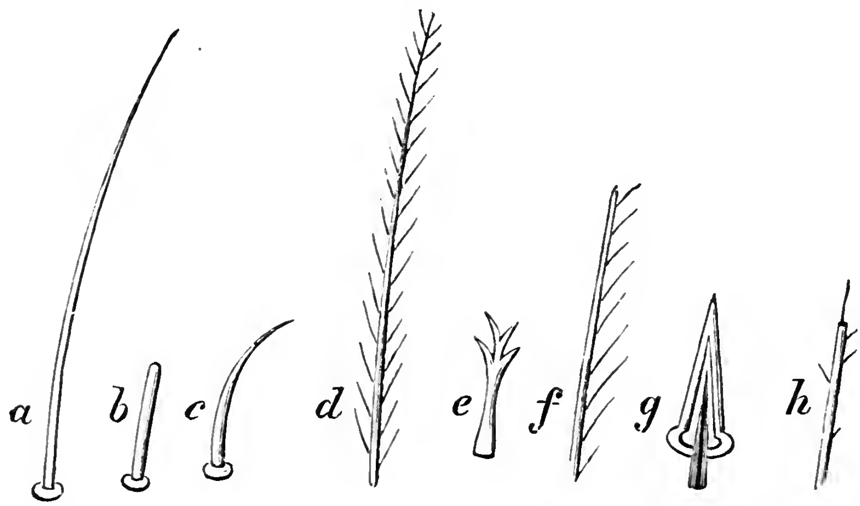


Fig. 5.—Hairs.

differ from ordinary hairs. In structure and length they vary considerably. Some are very short and others long, some straight and pointed, other feathery, and their uses are different. Whilst some act as organs of touch, and are called tactile, others are constructed for collecting and retaining pollen (Fig. 5, *d*), or for taking up minute quantities of liquids (Fig. 5, *e*). Again, there are others which act as brushes, and some that serve for protection and clothing.

The feathery hairs (Fig 5, *d*) consist of a shaft (*scapus*) and feathers (*radii*). The hairs on the drone are much coarser than those on either a queen or worker.

At some seasons black shiny bees are found, and formerly it was supposed that they were different from the others, but these only appear black from the loss of their hairs. The feathery hairs easily lose their

radii, which get rubbed off, and old bees are frequently found with radii only on one side (Fig. 5, *f*), or like *h* (Fig. 5). If we examine a bee we will find that its body is separated into three distinct regions, known as the head, thorax, and abdomen. Of these we shall treat in the following chapters.

CHAPTER IV.

THE HEAD OF THE BEE.

The Different Parts—Head of Worker, Queen, and Drone—Compound and Simple Eyes—Cheeks—Antennæ—Number of Joints—Mouth of Bees—Single and Double Parts—Labrum, Mandibulæ, Labium, Mentum—Labial Palpi and Maxillæ—Sucking Tube Formed—Ligula and its Muscles—Hairs and Papillæ—Bouton—Sheath—Rod—Single and Double Tubes—How Liquids are Sucked Up—How Small and Large Quantities are Taken—Connexion with Œsophagus—Gum Flap—Expansion and Contraction of Tubes—Tongue in Repose.

THE head (Fig. 6) consists of the *vertex*, or crown (*a*); the *genæ*, or cheeks (*b*); the face (below the vertex), the *clypeus*, or nose (*c*); the compound eyes (*d*); the *ocelli* or *stemmata*, simple eyes (*i*); the *antennæ*, or feelers (*f*) and the *trophi*, or organs of the mouth collectively (*p*, *h*, *g*, *e*).

The head (*caput*) differs in the three sorts of bees in shape, size, as well as in the disposition of the hairs.

The worker's head (Fig 6 and Fig 7, A) is triangular in appearance, slightly incurved at the vertex, and very wide at this part, with thickly-set hairs, and tapers rapidly towards the mouth. That of the queen (Fig. 7, B) is more heart-shaped, rather flattened at the vertex, and densely covered with long hairs. The head of the drone (Fig. 7, C) is in shape circular

when looked at from the front, has a small face, and is covered with strong tufted hairs.

At the back the head is concave, and corresponds to the convex part of the thorax, to which it is joined

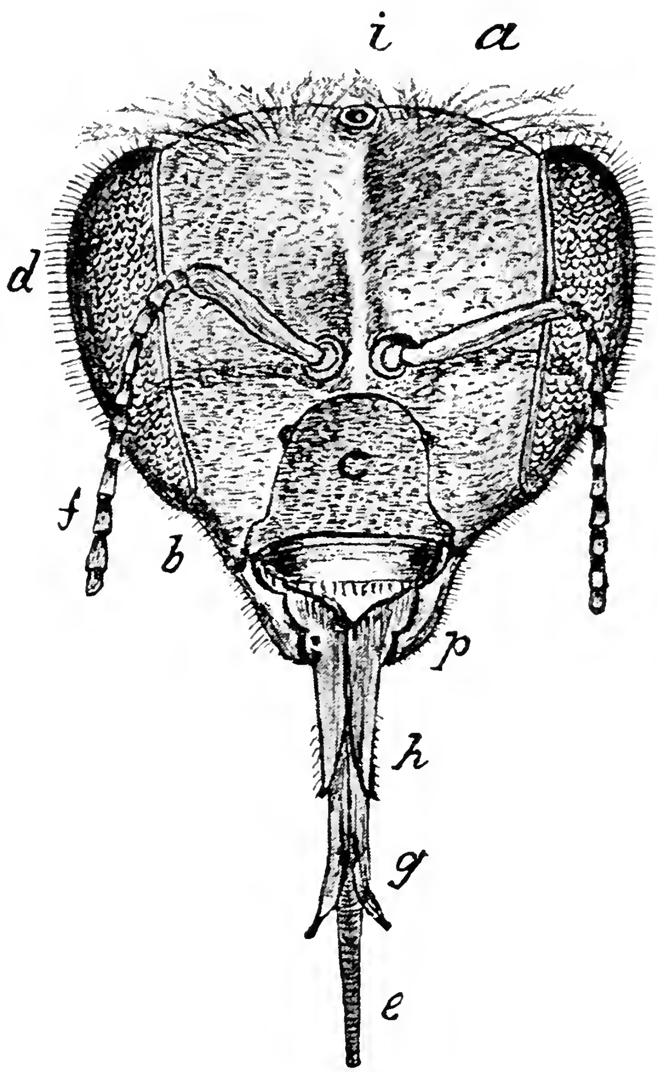


Fig. 6.—Head.

by a short neck. Looking at the side of the head, it presents the appearance of part of a sphere with rounded edges.

In the head, as we have seen, are situated the eyes, antennæ, and mouth parts.

The eyes of bees are of two kinds, two large faceted or compound eyes (Fig. 6, *d*), and three simple eyes (*ocelli*), of which one only is seen in Fig. 6, *i*.

The compound eyes are situated on each side of the vertex. They are very large in the drone and meet at the top. They are smaller in the queen and still smaller in the worker, and in both of these they do not meet, but leave exposed a large portion of the

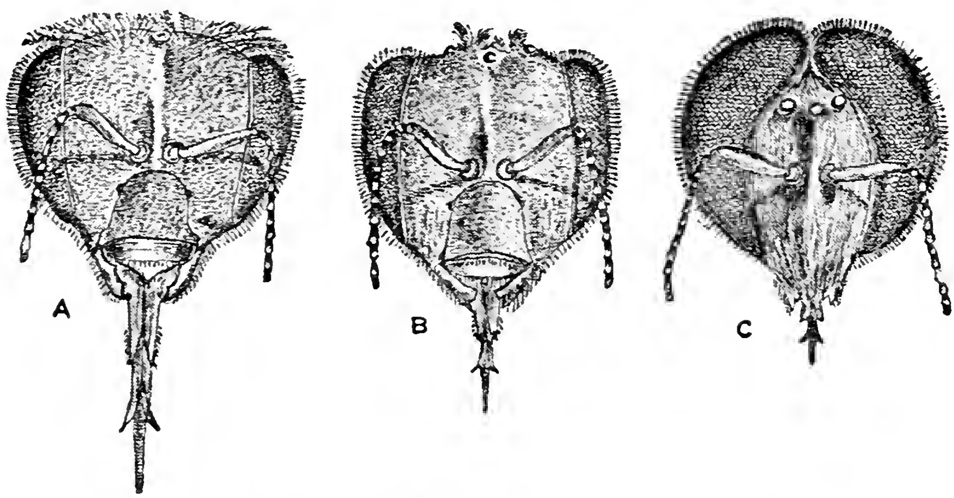


Fig. 7.—Head of Worker, Queen, and Drone.

crown. The compound eyes are not found in the larva, and yet from the simple organ of this are developed the marvellous eyes of the mature insect, with its thousands of hexagonal lenses, of which we shall treat more fully later. The simple eyes are placed upon the vertex in the queen and worker, amongst the hairs, and in the drone just below the angle formed by the junction of the two compound eyes, and are right in front of the face. They are three in number and are small, circular protuberances disposed in the form of a triangle, one eye at each angle, those of the drone being much closer together and nearly touching each other.

The face has a longitudinal *carina,* or prominent ridge, down its centre, which lies between the eyes, descending from the vertex to the base of the clypeus. The *genæ*, or cheeks, descend from the vertex laterally behind the compound eyes (Fig. 6, *b*).

The *antennæ*, of which there are two, are inserted in the centre of the face on each side of the carina (Fig. 6, *f*) and just above the clypeus. They are cylindrical and are jointed to the head by a hemi-

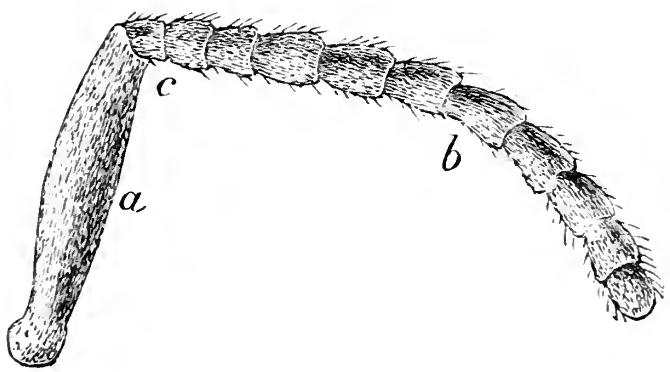


Fig. 8.—Antenna.

spherical joint (*radicula*), and being connected with the head by muscles, are capable of movement in all directions.

The antennæ comprise the *scape*, or basal joint (Fig. 8, *a*), and the *flagellum*, or terminal apparatus (Fig. 8, *b*), which are connected together by a thin membrane of chitine at *c* (Fig. 8).

The scape and flagellum (Kirby) collectively number thirteen joints in the drone and only twelve in the queen and worker. The relative lengths of the joints vary, the scape being the longest, and is in the drone about one-fifth and in the queen and worker one-fourth of the entire length of the antennæ. Examined with the microscope under a magnifying

power of 400 diameters, it will be seen that the antennæ are covered with hairs, which are very close on the terminal joints, and that they possess other organic structures, which we shall refer to in another chapter.

Collectively, the organs of the mouth are called *trophi* (Figs. 9 and 10).

They consist of the *labrum* (Fig. 9, *r*), or upper lip; the *epipharynx* (Fig. 9, *s*), or gum flap; the *pharynx*, or gullet, which forms the true mouth and entrance to the œsophagus; the *labium*, or under lip, which is formed of several parts, of which one is the *ligula* (Fig. 10, *e*), or true tongue.

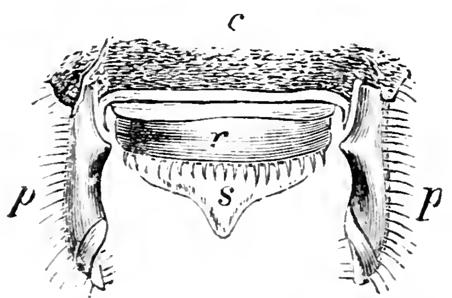


Fig. 9.

These parts are single; those in pairs being the *mandibles* (Fig. 9, *p p*); the *maxillæ* (Fig. 10, *k*, *h*); the *maxillary palpi* (Fig. 10, *i*); the *labial palpi* (Fig. 10, *g*, *f*), and the *paraglossæ* (Fig. 10, *n*).

The labrum, which is provided with a row of simple hairs along its edge in the queen and worker and tufted hairs in the drone, is attached by a joint to the clypeus (Fig. 9, *c*), has a vertical motion, and falls over the organs beneath it when in repose, and it is then itself covered by the mandibles.

The mandibles (*mandibulæ*) or jaws of bees, which are placed on each side of the labrum, move laterally. They are smooth and sharp along the edge in the worker (Fig. 9, *p p*, and Fig. 63, B), but are notched

in the queen and drone. They are used for a variety of purposes, being very hard and strong, and are pro-

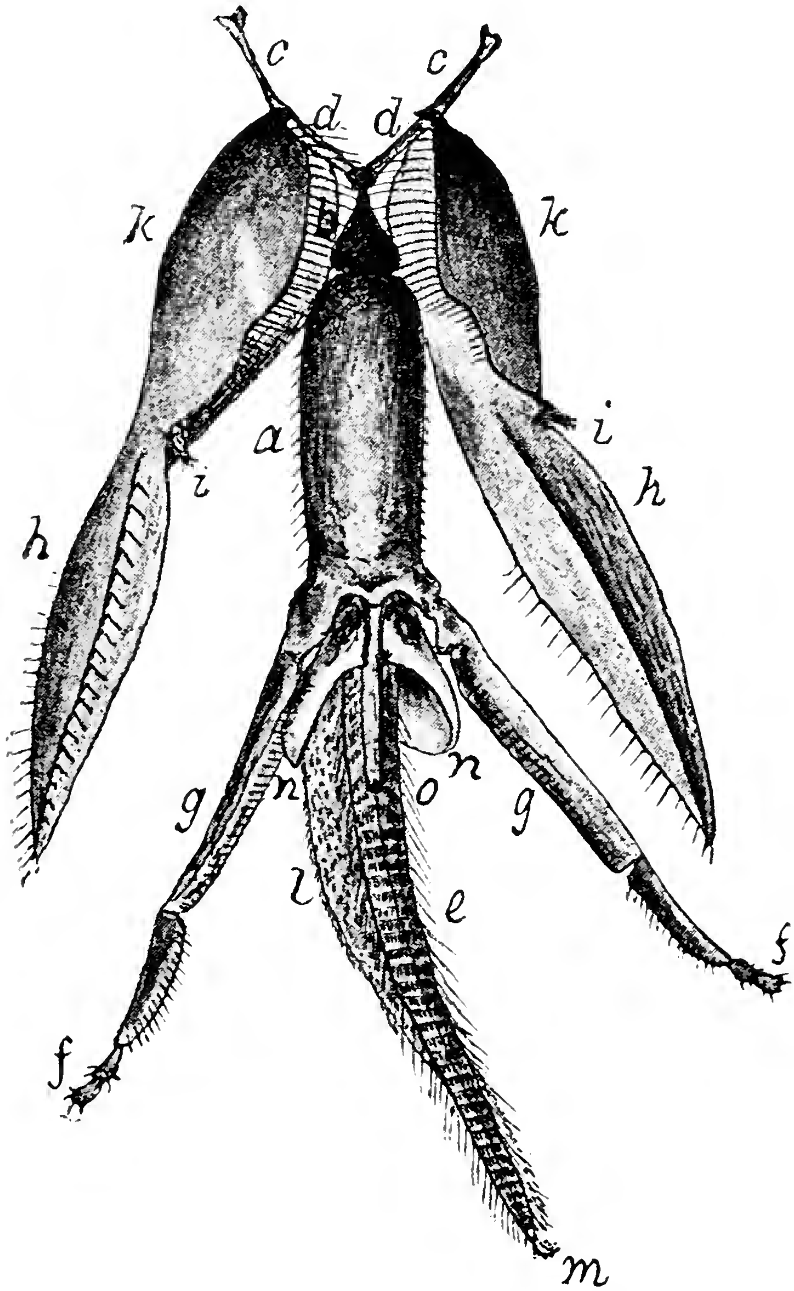


Fig. 10.

vided with powerful muscles, shown in Fig. 51, *g*. On the outside they are convex, whereas inside they are hollowed out something like a spoon, the con-

vexity being greatest in the jaws of the worker, less so in the queen, whereas in the drone it is hardly noticeable. The drone has the outside covered with hairs, which are much less numerous in those of the queen and worker, whose jaws, however, have a row of hairs on the inside (Fig. 51, *b*).

In describing the remaining mouth parts, we give the investigations of Dr. O. J. B. Wolff (170), which he published in 1874, and also of V. T. Chambers (23) in 1878, and J. D. Hyatt (70) in 1879, and T. J. Briant (12) in 1884, which clear up a great many of the hitherto obscure points.

The *labium*, or under lip, which forms the main stem of the rest, is composed of several parts. The strongly chitinous *mentum* (Fig. 10, *a*) lies at the upper extremity towards the back of the head, is joined to it by means of the *submentum*, or triangular *fulcrum* of Kirby (Fig. 10, *b*), which is connected to the *cardines* (Fig. 10, *c c*) by the *lora* (Fig. 10, *d d*), and is extensible and contractile at the will of the insect.

The mentum contains the muscles, which can draw the *ligula* (Fig. 10, *e*) partly into it. The labium is soft at the top and hard at the sides and underneath. It forms a knee-bend at part of its length. The labial palpi (Fig. 10, *g f*) are attached to the mentum on either side by a hinge-joint. They consist of four joints, the two at the extremities (Fig. 10, *f*, *f*) being very small, and are furnished with tactile hairs (Fig. 11, A), and have a number of transparent dots, described by Dr. J. Hicks (65) in 1860.

On either side of the labial palpi, and fastened to

the submentum by the cardines, are found the *maxillæ* (Fig. 10, *k h*), or lower jaws, so called from the function they perform. These are hollowed out and fit over the mentum on either side, and have stiff hairs along the front edges. They have also feelers (Fig. 10, *i*) called maxillary palpi, furnished at the end with hairs (Fig. 11, B), described by Dr. Hicks (65).

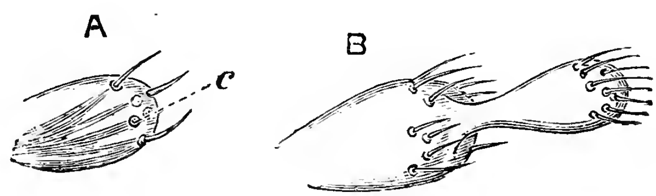


Fig. 11.—Labial and Maxillary Palps.

The maxillæ are composed of two joints, the upper harder part, called the stipe (*stipes*) (Fig. 10, *k*), having strong hairs along its front edge, and the lower more delicate part (Fig. 10, *h*) forming the blade (*lacinia*), furnished sparingly with hairs.

By referring to the sections taken from Wolff's (170) monograph (Fig. 13, A, B), it will be seen that the maxillæ (*m m*) and labial palpi (*l l*) together form a tube in which the enclosed tongue can move backwards and forwards.

In repose, or when the tongue is drawn in, it will be seen that the tube is flattened (Fig. 13, B), the tongue occupying the centre, so that in reality two tubes (*o o*) are formed, one on either side. When, however, the tongue is extended, the four parts assume the shape of Fig. 13, A, and form a large tube (*o o*). The first double and then single tube leads to the opening of the mouth. The *ligula*, or tongue (Fig. 10, *e*), is

attached to the mentum, and can be drawn in and extended by two muscles called the *retractor* and *protractor linguæ.* It is covered by a sheath on which are arranged rows of hairs (Fig. 12, *r*). These Hyatt (70) found to be short and triangular in shape at the base, long and spiny about the middle, smaller and more flexible near the apex.

Amongst these hairs there is a row of minute pits, with a central papilla (Fig. 12, *p p*), which have been described by Leydig (96), and Kraepelin (82), who suppose them to be organs of taste.

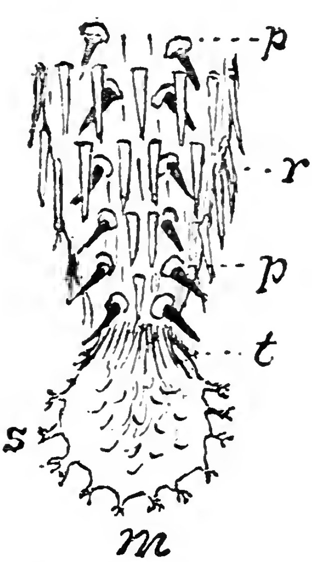


Fig. 12.—End of Tongue.

At the end is what is called the spoon (Figs. 10 and 12, *m*), or *bouton* of Réaumur (139), circular and concave, with a row of pale clavate hairs (Fig. 12, *s*, and Fig. 5, *e*) along the edge, and short hooked hairs on the inside, which Kraepelin also considers are for tasting, as they carry a minute opening at their ends.

At the narrowest part of the tongue, just above the spoon, there is a fringe of guard hairs (Figs. 12, *t*, and 14, B, *f*).

By referring to the section (Fig. 14, A), it will be seen that the sheath (*a*) passes round the tongue to the under side and is continued by a thin membrane (*b*) seen corrugated and covered with very short hairs. In Fig. 10, *l*, this part of the tongue in seen unfolded.

The membrane is continued to the rod (Fig. 14, A, *r*), which runs the whole length of the tongue and

is highly elastic, giving motion to the ligula in every direction. The rod has a groove on the under side $\frac{1}{1000}$ of an inch in diameter, along the edge of which are intercrossing hairs which convert it into a small tube. At the back the rod has a thick layer of muscles which serve to enlarge and contract the canal, thus making it a true sucking organ. The blood space is seen at *e*, the trachea at *g*, and *d* is the taste nerve. The closing of the sheath also forms two tubes (Fig. 14, A and B, *c c*). These, together with the groove, extend to the spoon, just above which the section (Fig. 14, B) is taken.

As appendages to the labium and partially surrounding the ligula at the upper end, are paraglossæ (Fig. 10, *n n*), membranous on the under side and strongly chitinous in front, and covered on the inside with very fine hairs. They are capable of meeting on the upper side and close over a groove on the tongue (Fig. 10, *o*), which extends a little way below them.

The structure of the queen's tongue is similar, except that it is shorter, with a smaller spoon, and the feeling hairs at the tip are larger. The drone's tongue is still shorter, and the spoon is very much smaller and quite rudimentary.

In order to understand that the bee does not lap honey and water, but sucks it up, we will consider the manner of action of the different parts which we have described. When minute quantities of nectar only are found in flowers, the spoon and groove on the under side of the ligula, as well as the two tubes

(Figs. 14, A and B, *c c*) are brought into play. By means of the muscular action of the rod (Hyatt, 70) the ligula is turned so that the hollow part of the spoon sweeps over the surface, and the branched hairs

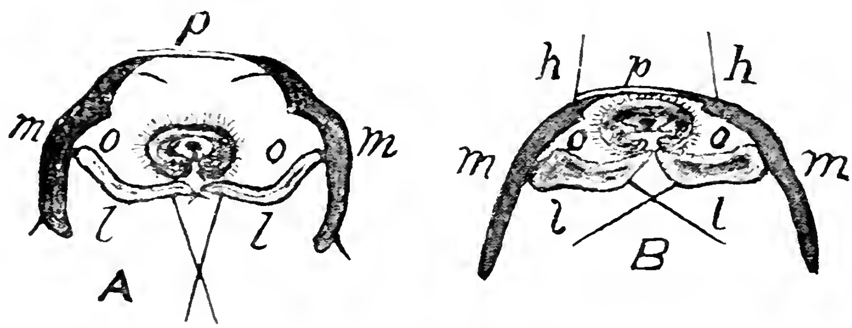


Fig. 13.—Section of Tongue enclosed by Maxillæ and Labial Palpi.

(Fig. 12, *s*) take up the most minute quantity of liquid. This is in turn transferred by the other hairs by capillarity to the groove on the under side, which is now turned uppermost. The connexion of the spoon with the ligula is here very small and is slightly hollowed, greatly facilitating the transfer. If the

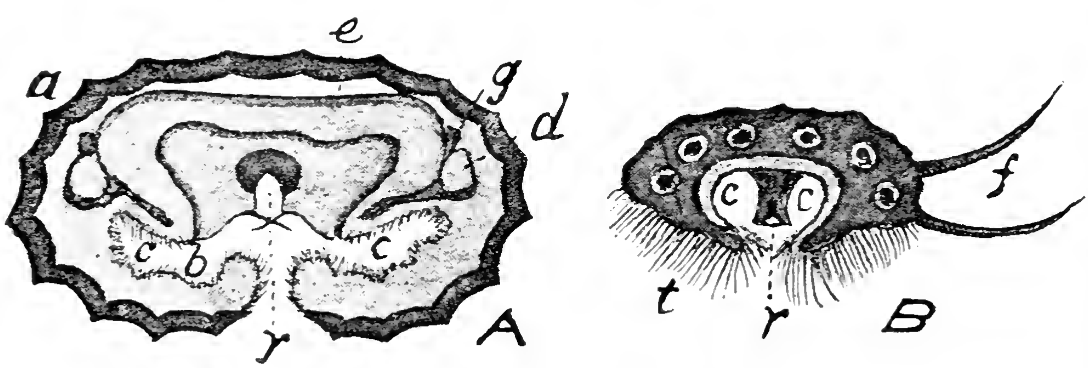


Fig. 14.—Section of Tongue.

quantity of liquid is sufficiently large, both the tubes and the groove are brought into use, but if the quantity is very small and not sufficient to fill them, the central groove may only be used. The liquid then finds its

way, partly by suction and partly by capillarity, to the paraglossæ, and is then conducted round to the groove (Fig. 10, *o*) on the upper side of the tongue, to be swallowed as we shall describe.

To understand how larger quantities are taken, we must now refer to Fig. 13, A and B. It will be seen that the thin plates (*p p*) of the maxillæ overlap each other and have a row of hairs (*h h*) which act as stops, and there is a groove on the inside for the same purpose. The labial palps (*l l*), with their intercrossing hairs, close the space below, and thus in conjunction with the maxillæ they form a tube (*o o*), in the centre of which the tongue moves backwards and forwards.

As the tongue takes up the liquid and the hairs become loaded, the tube (*o o*) comes into play. To complete the connexion with the œsophagus the gum flap (Fig. 9, *s*), is lowered on to the space left uncovered at the upper end of the maxillæ, and the tube is completed ready for suction.

It will probably be better understood by referring to the section through the bee's head (Fig. 23), showing disposition of the different parts. In this, *i* is the pharynx leading to the œsophagus, *a* the mentum, *e* the ligula, and *g* the labial palp, *k* the clypeus, and *u* the labrum. As seen in the illustration, there is no connexion with the pharynx, but when the mentum is brought up close to the opening and the gum flap at the extremity of the labrum (*u*) is brought down on the maxillæ, as we have explained, the tube is completed.

By placing the maxillæ and labial palps in the position shown at A (Fig. 13), the tube is expanded

and the liquid is drawn up; but on pressing them together, as in B (Fig. 13), two tubes (*o o*) are formed, whose capacity is much smaller than that of A, consequently the fluid is forced forward, just as it is in our own mouths. Bees are also able to distend the infolded membrane on the under side of the tongue and expose the rod, probably for the purpose of cleaning it.

In repose the mentum is drawn back, and the tongue (with the labial palps and covered by the maxillæ) is folded back out of the way.

CHAPTER V.

THORAX, LEGS, AND WINGS.

Formed of Three Parts—Muscles—Legs—Joints—Claws—Antennæ Cleaner—Second Leg Spur—Pollen Basket and Brush—Pincers—Comparison of Legs of Drone, Queen, and Worker—Locomotion—Pulvillus—Adhesion to Smooth Surfaces—Method of Examining—Wings—Hairs—Nervures—Cells—Hooklets—Method of fastening Anterior and Posterior Wings—How Flight is accomplished—Upward, downward, forward, and backward Flights—Number of Wing-beats demonstrated by graphic Method—Tracheal Distension—Specific Gravity altered—Muscles.

THE thorax is that part of the body of the bee which gives origin to the legs and wings. It is formed by the three segments which follow the head. The second and third rings support the wings. The presence of legs and wings involves a considerable development of the segments of the thorax, and particularly of the second and third, for there must be abundance of space within for the passage and attachment of the powerful muscles (Fig. 21), which, influenced by the will of the insect, move the legs and the organs of flight.

The first segment of the thorax, that which is nearest to the back of the head, is called the *pro-thorax;* the second, to which the first pair of wings is attached, is the *meso-thorax;* and the third, bearing the second pair of wings, is the *meta-thorax*.

The pro-thorax is reduced to a thin flexible neck, connecting it with the head. The thorax is thickly covered with downy hairs, and on the under side of the worker they are long and feathered (Fig. 5, *d*) for the purpose of holding pollen. On the thorax of the drone the hairs are short and very stiff, whilst in the queen there are not nearly so many underneath and between the legs as there are in the worker.

The Legs.

The bee has three pairs of legs. The first, or anterior legs, are attached to the pro-thorax; the intermediate to the meso-thorax; and the posterior or hind legs to the meta-thorax.

The three pairs of legs not only differ among themselves, but are also different from each other both in the drone, the worker, and the queen.

The muscles moving them are situated within the thorax.

By referring to Fig. 15, A, which represents the third leg of a worker, it will be seen that it is made up of nine joints: the first one (*a*), attached to the thorax, is the *coxa*, or hip joint; the *trochanter* (*b*) is a small conical joint forming the connexion between this and the next joint, the *femur* (*c*) or thigh; the *tibia* (*d*) or shank, and the *tarsus*, or foot. This is composed of five joints (*e*, *f*, *g*, *h*, *i*), diminishing in length from the first joint (*e*), which is as long as all the rest put together. In the anterior pair of legs the first joints are called *palmæ*, or palms, and in the four other legs, *plantæ*, or soles; the other

joints are called *digiti*, or fingers, or collectively the *tarsus*.

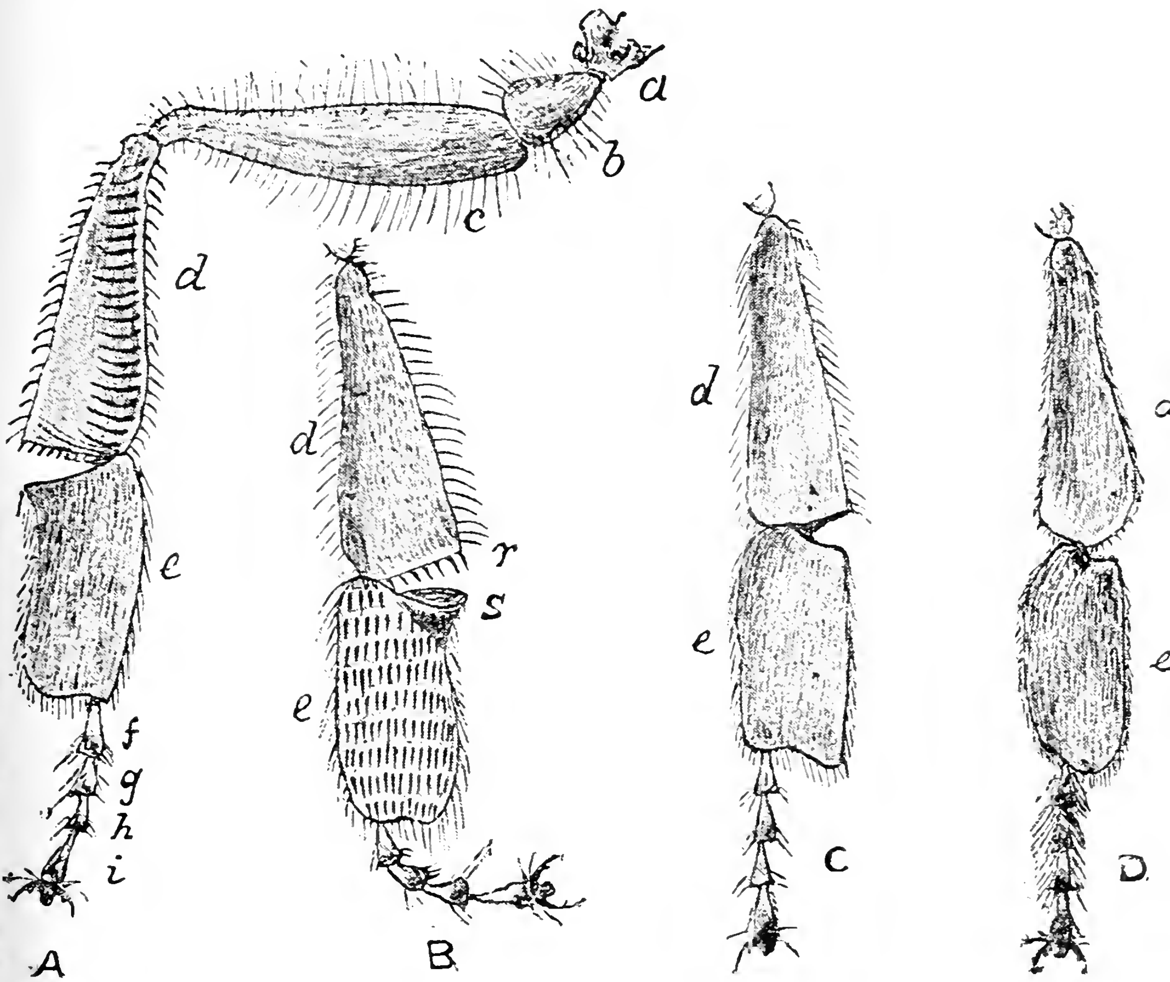


Fig. 15.—Hind Leg of Worker, Queen, and Drone.

At the extremity of the terminal joint (*i*) are the two claws (Fig. 17, *m m*), very hard and strong. They are hook-shaped, and have a smaller hooklet within.

These claws (*anguiculi*) enable the bees to suspend themselves and to hang on, the one to the other, as in comb-building, when placed in an empty hive. They have both lateral and perpendicular movements, and between their insertion is affixed the *pulvillus*, or cushion (Fig. 17, *n*).

In the first pair of the worker bee the coxa, trochanter, and femur have feathered hairs, those of the last joint being the longest. The tibia is connected to the femur by a hinge-joint, and is covered with simple and feathered hairs.

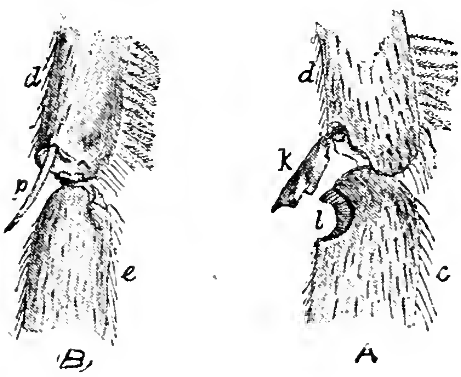


Fig. 16.—Details of Legs of Worker.

At the lower end of the tibia (Fig. 16, A, *d*) is a spine, *k*, to which is attached a *velum*, or sail, this being a small angular appendage fixed within the spine by its base.

The palma (Fig. 16, A, *e*) is thickly covered with strong hairs, which act as brushes.

Near the upper end, and on the inner side, there is a deep curved incision, called the *sinus*, terminating in the *strigilis*, curry-comb, or *pecten* (*l*), so named from the comb of stiff chitinous hairs which fringes its edge. Upon this the velum can act at the will of the insect, and combined they form a circular orifice. This device was illustrated and described by Kirby (76) in 1802, and subsequently by Shuckard (152), Girdwoyn (49), and others. Its function is to keep the antennæ clean, and free from pollen or other substances. When the insect wishes to clean one of the antennæ, it lays it within the sinus of the palma, and then, pressing the velum of the spine upon it, removes, by the combined action of the comb and the velum, all excrescences and soilure from it; and this process it repeats until satisfied with the cleanliness of the organ.

The operation may be frequently observed, and it would be noticed that the antenna on the right side is cleaned by this device on the left leg, and the left antenna by that of the right leg.

The remaining joints are provided with brushing hairs, and on the last, surrounding the claws, are long tactile hairs (Fig. 17, *o o*). These legs are similar both in the drone and queen, but the former has a number of feathered hairs on the digiti, or small joints of the tarsus.

In the second, or intermediate pair of legs of the worker, the sinus is absent, and instead of the velum, the tibia is provided with a spur or spine (Fig. 16, B, *p*).

Various guesses have been made as to its use, some supposing it was meant for removing the wax scales from beneath the abdominal rings; other fertile imaginations have stated it to be a tool for removing the pollen from the pollen baskets; but as it is found both in the drone and queen equally well developed, it being useless to them for this purpose, another idea, that of its being used as a collateral support, is a much more reasonable one (Shuckard, 152). Another statement has been made that it was for cleaning the wings, but it is far too short for this purpose.

The third pair, or posterior legs of the worker, serve as gatherers and carriers of pollen. The upper joints (Fig. 15, *a*, *b*, *c*) are covered with long feathery hairs. The tibia (A and B, *d*) is specially constructed for the conveyance of pollen and propolis, by being framed externally like a little basket, or *corbicula*. It is smooth, and hollowed longitudinally, and the lateral

edges are fringed with recurved hairs, which retain anything that may be placed in it (A, *d*). On the outside it is slightly hairy (B, *d*). Along the lower extremity it has a row of stiff bristles (B, *r*), called the *pecten*, or comb.

Just below is the planta, which is broad and slightly convex on both sides. It is joined to the tibia at one of the angles, and has a little projection (*s*) called the *auricle*, or earlet. On the outside (A, *e*) it is slightly hairy, but on the inner surface (B, *e*), that next to the body, it has short, stiff, chitinous, shiny, brown teeth, arranged transversely in ten rows of combs, projecting slightly from the surface. These are used for scraping and collecting the pollen which has got amongst the body hairs of the bee.

The articulation of the tibia and planta being at the interior angle, and the absence of the spur on the tibia (which only the honey bee does not possess), give the pecten (*r*) a freedom of action it would not otherwise have, and enable it to be used together with the auricle (*s*) on the planta, which is quite smooth, as a true pair of pincers, and as an instrument for laying hold of the thin flakes of wax, and for bringing them forward to be transferred by the other legs to the jaws for manipulation. The posterior legs of the queen (C) and drone (D) not being required as pollen-collecting instruments, are destitute of baskets, pincers, or combs, and are shaped differently. The legs of the drone, it will be seen, are the smallest, while those of the queen are the largest. As organs of locomotion, the structure of the legs has been studied and de-

scribed by many observers, and latterly by Dahl (28), Simmermacher (156), and Rombouts (143), the first two observers more particularly turning their attention to the method of attachment of the feet to smooth surfaces. Dahl says the six legs are necessary as climbing organs; one leg will always be perpendicular to the plane when the animal is moving up a vertical surface. As we know that three is the smallest number with which stable equilibrium is possible, an insect must have twice that number.

For moving on rough surfaces bees use their claws (Fig. 17, *m m*), which by their sharp tips are able to enter the smallest depressions, and so obtain a firm hold; but as these would slip on smooth surfaces, such as glass, another organ of fixation is provided. This organ, *n*, is situated between the claws, and is called the *pulvillus*.

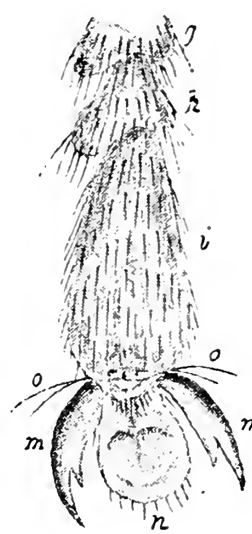


Fig. 17.
Pulvillus and Claws.

It is a fleshy lobule and almost smooth on the under surface, which gives out an adhesive secretion and causes it to adhere to a smooth surface. The upper surface is covered with very minute hairs, and when not in use the pulvillus is folded up and stands above the claws. Within there is an elastic rod (seen shaded in the illustration, which is taken from a photo-micrograph of the real foot), so that when this is brought down the pressure expands the pulvillus and spreads it over the smooth surface, the secretion

and pressure on the outside causing it to adhere. Dr. Rombouts (143) found there were on the under surface very minute hairs terminating in a kind of bulb, and from these flows an oily secretion which dries slowly and does not harden for a long time. He devised a very ingenius apparatus for examining the pulvilli by cutting a hole in a board and placing over it a glass. With the aid of a piece of paper gummed to the wings, the insect is introduced into the cavity in such a manner that the pulvilli rest on the glass. Then putting the board under the microscope with the glass side uppermost, this action was distinctly seen, as well as the liquid adhering to the glass.

When the claws have no foothold on a smooth surface they slip sideways out of the way, and the pulvillus which stood folded up above them is now brought down, adhering in the way we have explained. When the foot is lifted the pulvillus is stripped off the smooth surface and assumes its folded position again. The secretion being of an oily nature explains why bees cannot walk on smooth, moist surfaces, where their claws cannot take hold.

The Wings.

The bee has four membranous wings. The anterior or front pair are attached to the meso-thorax, and the posterior or hind wings to the meta-thorax. In repose the wings lie horizontally over the abdomen, the anterior above and the posterior beneath (Figs. 2, 3, and 4), and so close to the body that they enable the bee to enter cells in the combs without any difficulty.

The wings themselves are transparent membranes covered with very short hairs, intersected by threads darker than their substance, called nervures, veins, or ribs. These are hollow and thicker towards the root of the wing, allowing blood to circulate in them, and tracheæ also extend into them, the distribution of which corresponds to the course of the nervures.

The structure of the wings is well shown in Fig. 18.

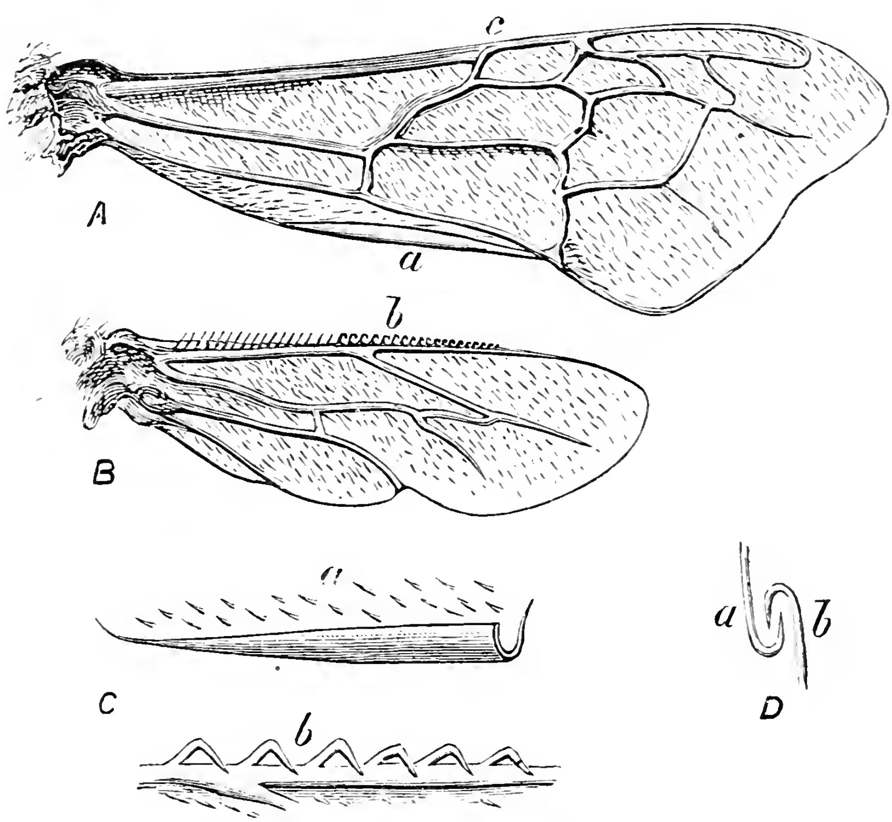


Fig 18.—Wings of Bee.

The main nervures beginning at the front edge, or *costa* (A, *c*), are called the costal, sub-costal, median, sub-median, and internal. The cells are also named according to their position in the wing, the first row

being the costal, then the sub-costal, median, and sub-median cells, and lastly the internal or anal cell.

Upon expansion of the wings in flight, the bee has the power of making the posterior wing, B, cling to the anterior, A, and this gives to the thus consolidated combination of the two a greater surface and force in beating the air to accelerate its progress and carry its body.

The outer margin of the posterior wing (B) is furnished with a series of hooklets (*b*) curved in an oblique direction similar to a corkscrew. The points are blunt, and the hooks, of which there are about twenty-three (sometimes less), decrease in size towards the end of the wing. On the anterior wing at *a*, corresponding to the position of the hooks, the membrane, which is here thicker, is folded under and forms a sort of trough. The trough and hooks are seen enlarged at C. When preparing for flight and the anterior wing is brought forward, this trough catches the hooks, which are turned up, and the wings are united, as seen at D, which is a section through trough and hooks on a larger scale. The insect has control over the operation of these hooklets, for on settling the wings are often seen raised perpendicularly over the back of the insect. Both wings are slightly convex on the outside. Professor Marey (107) has experimented on the flight of insects, and has carefully described the movements and position of the wings in their progress backwards and forwards through the air, although he disagrees in some respects with Pettigrew (126) and Amans (1). We do not intend to enter into the controversy, as

their views are all more or less based upon theories which would take too much of our space to discuss.

If we refer to Fig. 18, we shall see that the costal nervure (*c*) is a strong chitinous rod, running along the edge of the wing and tapering to its extremity. It is this nervure, Marey says, which, carried up and down by the elevating and depressing forces in the muscles actuating it, moves the wing. As an experiment, if the wing of an insect be taken off and exposed to a strong current of air, it is seen that the plane of the wing is inclined more and more as the current becomes stronger.

By referring to Fig. 19, A, it will be seen that when the current is in the direction shown by the arrow, the anterior nervure (*c*) resists, but the membranous portion bends, owing to its greater pliancy. If we blow on the opposite surface, we see this carried backwards, as shown in B.

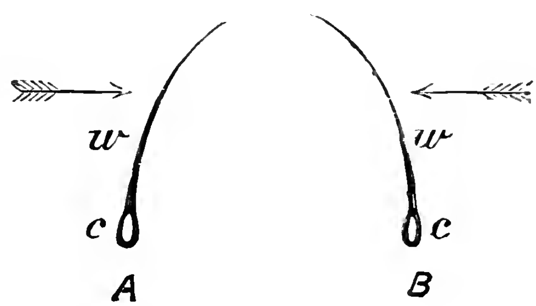


Fig. 19.—Diagram illustrating Pressure of Air on Wings.

It is evident that in the movement which takes place during flight, the resistance of the air will produce upon the plane of the wing the same effects as the currents of air just employed. The changes in the plane caused by the resistance of the air are just those which occur in flight. The descending wing presents its upper surface forwards, from the resistance of the air from below upwards; and the ascending wing turns its upper surface backwards, because the

resistance of the air acts upon it from above downwards.

The wing which descends has at the same time a forward motion, and the inclination taken by the plane under the influence of resistance causes the oblique descent. An inclined plane which strikes the air has a tendency to move in the direction of its own inclination, therefore the insect is propelled forwards. In an ascending wing the plane is reversed, by which means the forward motion is still maintained. Marey found that owing to the slight bending of the nervure the tips of the wings really described a figure 8.

He illustrated these movements mechanically, by means of an instrument carrying a rod, to which was fixed a membrane similar to an insect's wing, and by moving this rapidly in a vertical plane between two candles, he demonstrated that, by the pushing aside of the membrane, at each alternate movement the air, acted upon by the wing, received an impulse in an opposite direction. In the candle placed by the thin edge of the wing, the flame is strongly blown away by the air produced. In the front of the wing, on the contrary, the flame is strongly drawn towards it, showing that the current of air is in the same direction both in the upward and downward movement of the wings. The wings, in part, act, Marey says, as a propeller does in water, or as an oar, when used in the stern of a boat, propels it forward.

Bees, as we have said, and as every bee-keeper will have noticed, can fly backwards, and can stop when they like, almost suddenly. This is accomplished by changing the inclination of the plane of

oscillation of its wings, which can be done, Marey says, by moving the abdomen so as to displace the centre of gravity ; so that the insect can, according to its wishes, increase the rapidity of its forward flight, lessen the speed acquired, retrograde, dart towards the side, or ascend and descend.

It is easily seen that when a bee flying at full speed stops upon a flower, it directs the plane of oscillation of the wings backwards with considerable force.

Marey was able to demonstrate, by means of models, this theory of flight in insects, and by the 'graphic method' he was able to show that the two wings act simultaneously, and that both perform the same number of movements.

This was done by the graphic method in the following manner :—A sheet of paper, blackened by the smoke of a wax candle, is stretched upon a cylinder, which revolves at the rate of one turn in a second and a half. The insect is so held that one of its wings brushes against the blackened paper at every movement. Each of these contacts removes a portion of black on the paper, and as the cylinder revolves, new points present themselves continually to the wing of the insect. Thus regular marks at certain distances are obtained. As the cylinder revolves once in a second and a half, it is easy to see how many strokes of the wing are marked on the circumference ; but it is sometimes convenient to use a chronographic tuning fork provided with a fine point, which grazes the paper, and to register near the figure traced by the insect the vibrations which the style makes.

In Fig. 20 the marks made by the bee's wing are shown at *b*, while *a* represents the curve produced by the tuning fork, which makes a double oscillation 250 times a second. This enabled Marey to determine as 190 the number of vibrations of the bee's wings, as he found this number registered in the same space occupied by the 250 vibrations of the tuning fork. In his

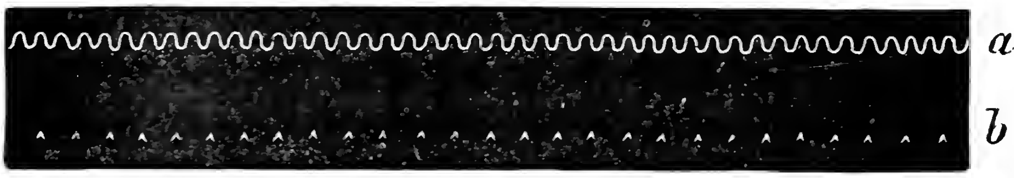


Fig. 20.—Graphic Representation of Vibration of Bee's Wing.

experiments he found that, by diminishing the contact of the wings on the cylinder, and thus reducing friction, the velocity was still greater, so that this number cannot be reckoned as the highest a bee is capable of attaining. The corroboration of this theory, Marey says, is found in the experiments which many naturalists have made. All these experiments prove that the insect needs for the due function of flight a rigid main rib and a flexible membrane.

When treating of tracheæ, we shall see how these are filled when the bee is preparing for flight, for at other times, when they are not so filled, they are not able to fly. Young bees do not fly, and it is not until they are several days old that their tracheæ become sufficiently charged with air to enable them to do so.

Wolff (170) has explained clearly how the air sacs in the thorax are filled with air during flight.

Fig. 21 is a section through the thorax of a drone, showing the muscles (*a*, *b*, *c*, and *d*) surrounded by the air cavities (*e*), from which enter a large number of tracheæ, to supply the necessary air to these muscles.

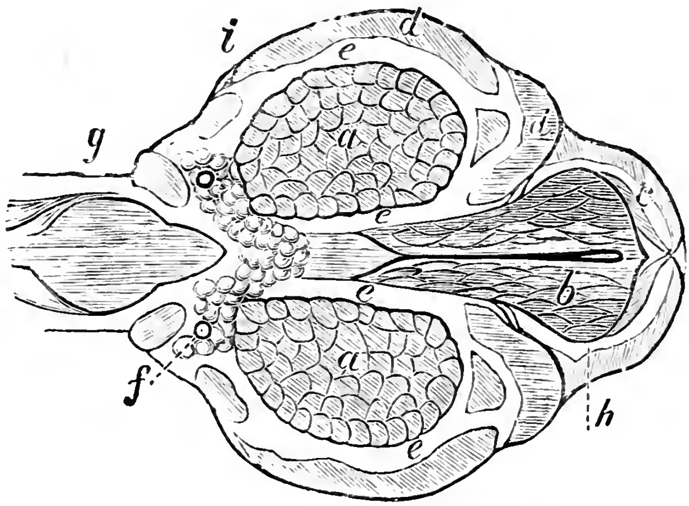


Fig. 21.—Section through Thorax.

When the wings are in repose, the air cavity surrounding the muscles becomes very small, as it is nearly filled with them, but as soon as these (Fig. 21, *b*), which are called *depressor alarum*, or wing depressors, contract, the *mesophragma* (*h*) is forced away from the meta-thorax upwards and forwards. This enlargement of the cavity draws in a quantity of air, which, on relaxation of the muscles, is forced into the tracheæ. With these and other movements the bee is able to fill its air sacs with air, and so alter its specific gravity as to enable it to fly as explained. The other muscles in the figure are called *levator alarum* (*a*); the *antagonist* of depressors (*c*); and (*d*) the *posterior wing* muscles.

In the worker the wings extend to within the last ring of the abdomen.

The structure is the same in the queen and drone. In both the wings are longer than in the worker. In the queen they extend half-way over the abdomen, and on the hind wing there are about twenty hooklets. In the drone they are still longer, and cover the abdomen, while the hind wing is very much broader and stronger, and is provided with twenty-four hooklets. The number of hooklets varies considerably, and we have found that sometimes there are not the same number on both sides; but they generally range between the lowest number of fifteen, in the queen, to twenty-five, the highest number in the drone.

It is very difficult to fix with certainty the distance to which bees are able to fly and their rate of flight. Careful observations have, however, shown that they usually work within a radius of two miles from their hives; but if food is scarce they will fly further in search of it, and have been known to go as far as four or five miles. In mountainous districts the currents of air and temperature have an influence on the flight of bees, and it has been observed that, although they will work in the plains within a radius of two miles, they rarely rise to pastures above four hundred yards. The rate of flight is more difficult to determine, but we have ourselves driven at the rate of twelve miles an hour and seen bees keep up with this speed for some distance, and even exceed it. The speed is, however, in a great measure regulated by the load the bee has to carry, and in returning laden to the hive bees fly much more slowly than when they leave it in search of food.

CHAPTER VI.

THE ABDOMEN.

Of Worker—Petiole—Rings—Pygidium—Dorsal and Ventral Plates—Expansion and Contraction—Wax Plates—Length in Queen and Drone.

THE abdomen of the worker, which is connected to the thorax by a very short tube, *petiole* (Fig. 22, *a*), is made up of six imbricated rings of chitine, which gradually diminish in size towards the end (*pygidium*, *g*). Each of them is made up of two plates; the *dorsal*, or those on the back, are the largest, and overlap the smaller *ventral* plates found on the under side. Each of these rings is connected with the next by means of a thin chitinous membrane, which, by creasing, allows one plate to pass over the other, and at the will of the insect the abdomen can be expanded or contracted. The dorsal plates are fringed with hairs. The first ventral plate is small and rounded off at the upper edge, whereas the last one is heart-shaped, and those between the two are shaped somewhat like a saddle, and slightly convex on the outside. In these four plates (*c*, *d*, *e*, *f*) the exposed part consists of hard and dark-coloured chitine, and the part which is covered is much thinner. It has a framework of hard chitine, which encloses on each side two five-sided perfectly clear transparent surfaces, on which the plates of wax are formed. The uncovered parts of the eight scales

are seen white in the illustration, and we shall go into a description of them more fully when treating of the wax organs. The exposed part of each plate is covered with feathered hairs, which gradually diminish in length towards the end.

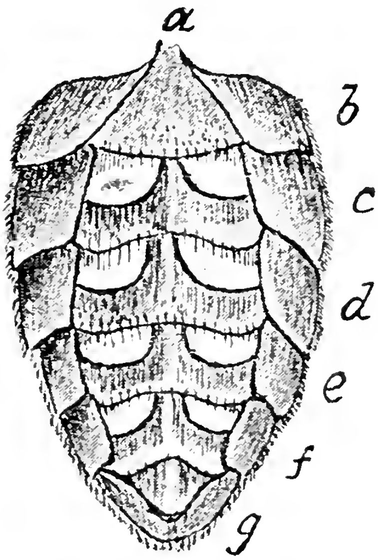


Fig. 22.
Abdomen of Worker.

The queen, whose abdomen is longer than that of the worker, has also six segments, but they are wider, and the ventral plates are devoid of the thin membranous surfaces of the worker. Likewise, instead of the feathered hairs, the plates are covered with very fine short hairs resembling down.

The drone has seven rings, and the ventral plates are much narrower, nor have they the transparent membranes, but are provided with a few stronger feathered hairs.

The first dorsal plate of the drone is also fringed with hair, and the fifth and sixth plates are covered with very long hairs. The abdomen of the drone is also much longer than that of the worker.

CHAPTER VII.

INTERNAL STRUCTURE.

Endo-skeleton—Mesocephalic Pillars—Corrugations of Thorax —Mesophragma.

ALTHOUGH we stated at page 15 that the bee had neither bones nor cartilaginous framework, the skeleton is not entirely external. There are braces of chitine, corrugations and webs of the same material, which strengthen weak parts. These are called the *endo-*

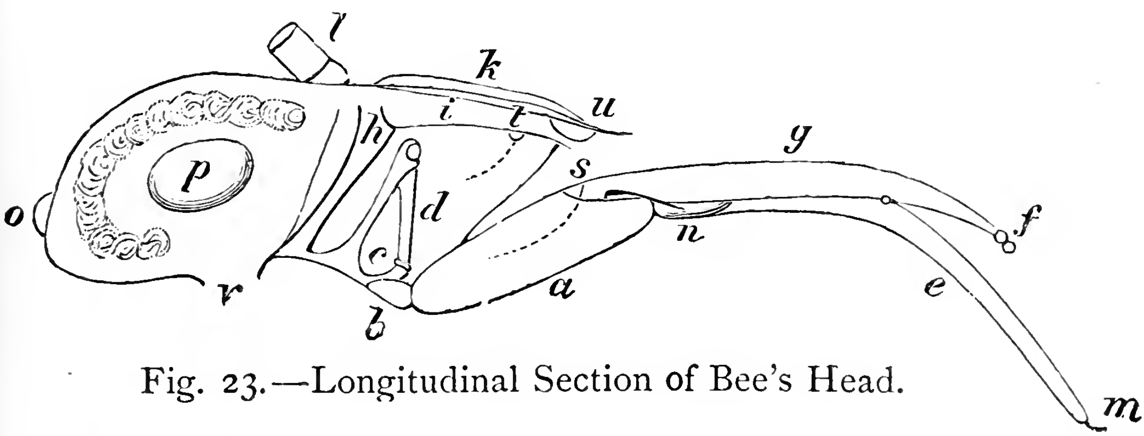


Fig. 23.—Longitudinal Section of Bee's Head.

skeleton. Macloskie (105), who has studied the internal skeleton of the head, found the clypeus bent down at its posterior edge into a hard transverse ridge, with thick outgrowths at the posterior angles. From these outgrowths descend pillars (called *meso-cephalic*) obliquely from the front to the back of the head. These pillars (Fig. 23, *h*) are inserted in the back of the skull close to the opening (*v*).

Fig. 24 is a diagram of the transverse section of the skull, showing the disposition of the endo-skeleton. The clypeus has to support the mandibles and to

afford attachment to many muscles, therefore it has to be very much strengthened. To give it more extensive support the top of each pillar is forked (Fig. 24, *h*). It is these pillars which make the bee's head so strong, though its external skeleton is thin. Macloskie found that these pillars ascend in front of the central brain-lobes, running between them and the ophthalmic lobes, and keep the large ocular apparatus in its place.

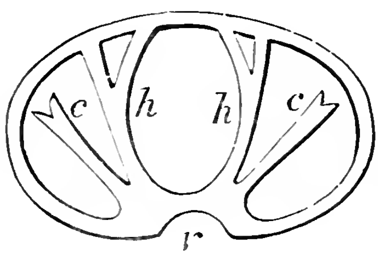


Fig 24.
Diagram of Transverse Section Head of Bee.

Then, close to the bases of these pillars, rods (Fig. 23, *c*) rise and run forward towards the front of the head. They are firmly fixed, widen out at the root, and are slightly pliant, their motion being limited by a web which binds them to the base of the head. These rods are forked at the ends and support the *lora* (Kirby, 76) (Fig. 23, *d*), jointed by a very perfect elbow joint, and which also gives support to the maxillæ. The position of these rods is shown in transverse section at *c*, Fig. 24.

The thorax, as the source of locomotion, has a very great strain upon it, and to prevent it collapsing we find the difficulty overcome by corrugations and plaitings of the external skeleton, besides strong webs to give it great rigidity. There is also a stiff plate called the *mesophragma* (Fig. 21, *h*) which lies between the meso- and meta-thorax, and gives attachment to some of the powerful muscles which move the wings.

CHAPTER VIII.

RESPIRATION.

Breathing Apparatus—Spiracles—Tracheæ and their Structure—Spiral Filaments—Communication between Tracheæ—Air Sacs—Smaller in Queen—Use of Air Sacs—Specific Gravity Altered—Anterior Spiracles the Largest—Inspiration and Expiration.

THE bee, like most other insects, does not breathe as we do, through apertures in the head, but air is admitted by special openings provided for this purpose situated on the surface of the body. These openings are called *spiracles* (frontispiece, *s*), and there is a row of them on each side of the body. They are supplied with a mechanism by which they can be voluntarily closed, and their structure has been studied and described by many investigators, more particularly by Newport (116), Landois (88), and Krancher (84).

Each spiracle consists of two openings, one behind the other. The inner one can be closed by a valve, and the outer one is provided with short hairs along the edge of the opening, to prevent dust and other impurities from entering. Their structure will be more fully explained when we treat of the voice of the bee, in the production of which they play so important a part.

The spiracles are the openings leading to internal tubes, called *tracheæ*, which branch in all directions through the body of the insect (see frontispiece and Fig. 26).

There are two pairs of spiracles in the thorax, viz.,

a front pair on the pro-thorax and a hind pair on the meta-thorax (Krancher, 84). There are also five on each side of the abdomen; in all, fourteen in the queen and worker, whereas in the drone there are sixteen, there being an additional abdominal ring. All the abdominal rings except the last one have a pair of spiracles, but they are never found in the head or in the last abdominal segment of insects.

The structure of the tracheal tubes has been described by Sprengel, Swammerdam (158) Newport (116), and others. The embryogeny of insects, according to Weismann, Girard says, has shown that the tracheæ are developed by invagination of the outside skin, and that at the moulting the tubes in the proximity of the spiracles are cast off.

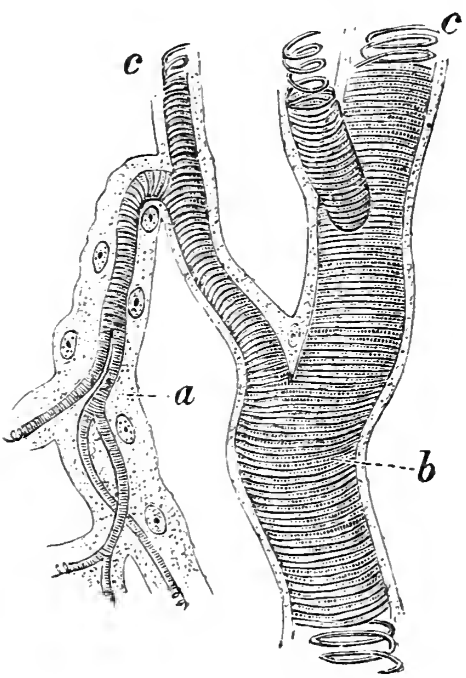


Fig. 25.—Tracheæ.

The tracheæ are formed of two membranes, an external *serous* (Fig. 25, *a*), and an internal *mucous* (*b*), enclosing within them a spirally convoluted elastic fibre (*c*).

The external membrane is loosely attached round the spiral, and the whole of the internal lining is continuous with the external skin of the body of the insect, therefore, by this invagination, the outer skin is the inner one of the tracheæ. The spiral filaments are not independent structures, but are crenulations, or

inward foldings, with thickening of the chitinous wall. They are really tubular, fissured at the line of infolding, and continuous with enclosing wall. During the time of moulting in the larva the inner lining, with the spiral, is cast off with the outer skin.

The spiral is capable of much compression, so that the quantity of air contained in any trachea may vary according to circumstances. It can only be stretched to a very slight extent without rupturing the membrane, and when this takes place at most five turns of the spiral (Fig. 25, *c*) can be separated (Sedgwick-Minot, 151).

Each set of vessels consists of from eight to twelve tubes, which originate in a bundle from the longitudinal tracheæ, and distibute their branches over the stomach and other viscera, sending minute ramifications to every part of the body, even to the substance of the brain and nerves. The longitudinal tracheæ communicate freely with each other across the body and along the whole dorsal and ventral surfaces by small ramifications from each side meeting (Fig. 26, and frontispiece). They are also extended to the antennæ, wings, and legs. By means of these tracheæ air is carried to every part of the body.

The principal tracheæ in the bee, as in all flying insects, are developed into large *vesicles*, or air sacs (Fig. 26), and as these are only dilated tracheæ their structure is similar, although the spirals are in a very attenuated state and hardly perceptible. The principal and largest air sacs are placed in the anterior part of the abdomen, and form, with those that follow

them, freely communicating respiratory cavities, whilst the tracheæ which issue from them are dilated into a series of funnels, which communicate with each other across the body by their finer ends. The air sacs of the drone are similarly placed, but those of the queen are considerably smaller, much of the space in the abdomen being occupied by the large ovaries.

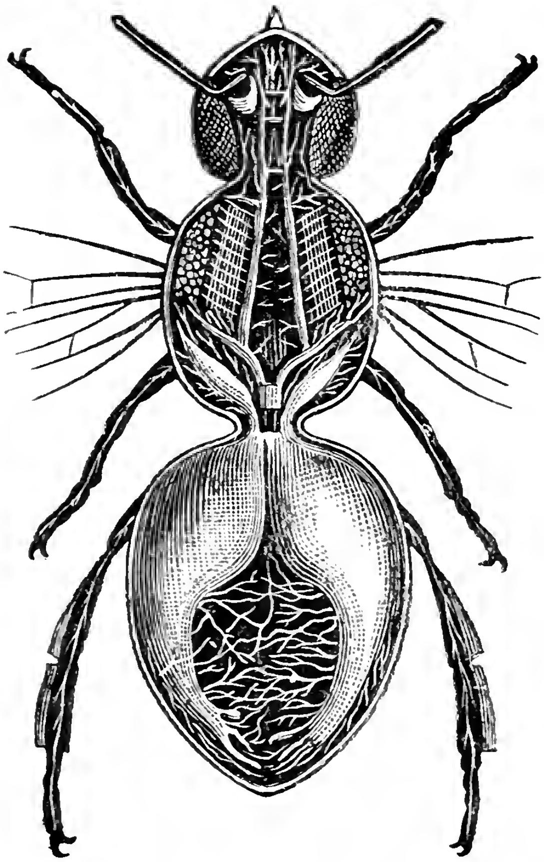


Fig. 26.—Aerating System.

As the abdomen of the bee is alternately contracted and extended, air is drawn into and forced out of these tubes through the spiracles.

The real use of the air sacs is, as Hunter supposed, to enable the insect to alter its specific gravity at pleasure by enlarging its bulk, and thus render it better able to sustain itself on the wing with but little muscular effort (Newport, 116).

In the act of respiration nearly all the muscles and nerves of each segment of the body are brought into constant action. Réaumur (139) found by his experiments that the anterior spiracles are the largest and most fully developed, and are the most important to the insect in the act of respiration. Each longitudinal extension of the segments of the abdomen

corresponds to each inspiration and their contraction to expiration.

Vogel (166) says when a bee is quiet it takes three to five inspirations, then the abdomen remains still for two to three minutes, and then the rings expand again three to five times in a second, again to rest for two to three minutes. Young bees, when they first fly out, take more inspirations, which are also much more rapid, so that it is difficult to count them.

When the insect prepares for flight, at the moment of elevating its wings the anterior pairs of spiracles are opened in the act of inspiration, and the air rushing into them passes into the tracheæ of the whole body, distending the air sacs, and rendering the insect of less specific gravity, so that when the spiracles are closed, at the instant when the bee endeavours to raise itself in the air, it is enabled to sustain a long and powerful flight with but little expenditure of muscular power. In Fig. 21, at *e*, are shown the air sacs in the thorax surrounded by the powerful muscles.

Newport (116) found that the quantity and rapidity of respiration has some relation to the muscular power of the insect in a state of activity. In a normal state he found the inspirations to seldom exceed forty per minute, whereas he counted from 110 to 160 contractions of the abdominal rings per minute when the insect had been much fatigued.

CHAPTER IX.

BLOOD CIRCULATION.

Circulating System—Dorsal Vessel—Ventricles—Graber's Discovery—Pericardial Diaphragm—Pericardial Cavity—Blood of the Bee—Speed of Circulation alters with Temperature—Heat of Blood—Temperature of Cluster connected with Activity of Respiration—Experiments on Winter Temperature of Cluster—Temperature at Different Seasons.

Bees, like all other insects, have organs of circulation, although they have no regular system of blood-vessels like the higher animals. Although Swammerdam, Malpighi, and Lyonnet had an idea of the method of circulation in insects, it was not until Newport (119, 120) explained the matter that a proper knowledge of the process was arrived at, and the still more recent discoveries of Graber (51, 52, 53), in themselves of the highest importance, have cleared up what was uncertain and for so long a time contested.

The dorsal vessel (Fig. 27), which is a heart containing a series of cavities, or *ventricles*, is situated immediately under the external covering of the back of the insect, and extends from near the end of the abdomen, where it is closed, to the head above the œsophagus, where the tube is open near the brain.

The walls of the heart are made up of three layers, a thin inner lining (the *endocardium*) attached to a central striated muscular wall, and an outer coat of connective tissue (*pericardium*). In the queen and

worker there are five ventricles, and each is provided with an opening on either side (Fig. 28, *a*), which acts, by muscular contraction, as a valve.

Each ventricle communicates with the one before it by means of a similar valve (Fig. 28, *b*), so that the blood flows

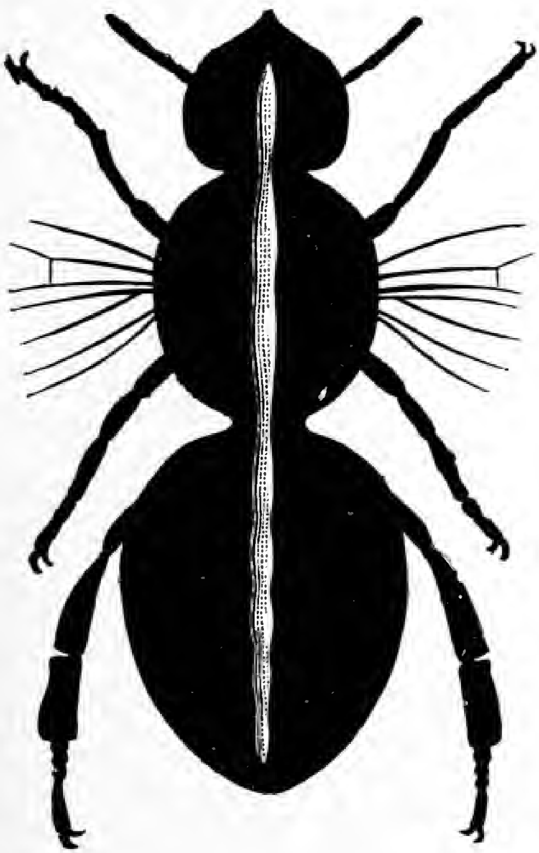


Fig. 27.—Dorsal Vessel.

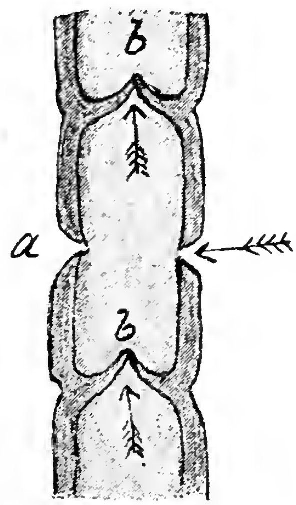


Fig. 28.
Ventricles and Valves.

in one direction (indicated by the arrows in the figure), when the dorsal vessel is contracted by means of the central muscular layer, and is forced out at the head, returning thence and permeating every part of the body. When the ventricles are expanded the blood enters by the side openings, and the valves between them close, but again on contraction the reverse takes place, so that there is a constant stream of blood flowing to the head.

The dorsal vessel is kept in its place by muscles

which surround it and join the dermal skeleton. Beneath are situated the complicated muscular plates, which are designated by Lyonnet as wings, not connected with the dorsal vessel, but which form a diaphragm, separating the body of the bee into two very unequal divisions, the smaller, or dorsal, above, and the larger, or visceral, below. The muscles of this diaphragm are very complicated, for besides the intercrossing of the muscular fibres on each side, under the dorsal vessel, there are even on the same side complex inosculations* among themselves.

This *pericardial diaphragm*, as Graber (52) calls it, in contracting drives back the viscera, and in consequence of the enlargement of the upper or pericardial cavity resulting from it, the blood is forced through the opening into the dorsal vessel. This rests on the yellow *pericardial nucleated cells*, 0·035 mm. in diameter, forming a cushion. Sometimes these extend filaments to the outer layer of the heart, or the diaphragm. There are also fatty bodies (*Fettkörper*, Graber, or *corps graisseux*, Girard), containing here and there what Graber calls '*eingesprengte zellen*' (*cellules enclavées*, Girard), or enclosed cells, of yellow colour, always with a single nucleus, resisting the action of acid and alkaline solutions. Amongst these there are nerve filaments and numerous tracheal ramifications, covering the dorsal vessel, and intercalating themselves between the pericardial cells.

* Union of two vessels of an animal body at their extremities, or by contact and perforation of their sides, by which means a communication is maintained.

These last are the ends of the finest tracheal ramifications, the peritoneal * membrane of the tracheæ, uniting with the external membrane of the pericardial cells.

By this discovery of Graber's it is seen that the blood can be supplied with oxygen by the numerous tracheæ diffused throughout the body, and also, being oxygenated at last in close proximity to the dorsal vessel, it enters it to be propelled to the brain, and from thence to every other part of the body.

The blood of the bee, like that of other insects, is colourless, and contains white corpuscles, which are less numerous than those found in the red blood of vertebrate animals. They have a cellular character, containing protoplasm and a nucleus surrounded by granular matter. They are analogous to the white blood corpuscles of vertebrates, and are constantly changing their shape, like amœbæ, and are therefore called *amœboid.* Sometimes they are round, then ellipsoid or boat-shaped, or ragged at the edges, or pointed, and even star-shaped.

Newport (120) and Graber (52) remarked that the speed of circulation altered with the temperature, and also that this has much to do with the number of pulsations of the heart, which cease at freezing point, and are more and more active in proportion to the rise in the temperature. The blood of the bee has a certain amount of specific or animal heat. Ancient

* Belonging to the peritoneum, a thin, smooth, serous membrane, investing the whole internal surface of the abdomen, and more or less all the viscera contained in it.

observers have recognised the fact that a certain warmth is always found in a cluster of bees, even in winter.

The temperature, as Newport (120) has shown, is intimately connected with the activity of respiration and the agitation of the bees. It is by close clustering that they can raise the temperature they find necessary for comb-building. In 1878 we carried out a series of experiments to test the amount of heat in a cluster of bees in winter, for Newport had stated that it fell sometimes below freezing point. Our experiments were carried out with extreme care on four hives in a bee-house, and although the outside temperature and that in the bee-house frequently fell below freezing point, on only two occasions did the temperature of the cluster fall below 60 degrees. On the occasions when we found it below this, the hives were opened, and revealed the fact that the cluster had moved away and left the thermometer exposed.

The temperature inside the cluster ranged from 60 to 70 degrees Fahrenheit. At different seasons the temperature inside the hive varies, and Newport found that during the swarming season more heat was produced, even with a lower external temperature, than in the month of August. In the former case he found it as high as 96° Fahr., with an outside temperature of 66° Fahr., whilst in the month of August it is seldom more than 80°, or perhaps 86°, even in the middle of the day, when the temperature is often more than 78° Fahr. Less heat is in reality produced from the same volume of air consumed at the high tempera-

ture of 78°, than when the atmosphere is not more than 66° Fahr., as is often the case at the time of swarming, while in reality a far less volume of air is consumed in August than in May, because the bees are not in the same state of excitement.

Girard (46) has also shown by experiments that the temperature of the thorax is always in excess of that of the abdomen, in consequence of the more rapid respiration caused by the movement of flight.

CHAPTER X.

NERVOUS SYSTEM.

Ganglionic Chain—Brain, or Supra-œsophageal Ganglion—Nerve Fibrils—Ganglionic Cells—Regulation of Animal Life—Commissural Fibres—Reflex Action—Ganglia connected with Wings and Legs—Number of Ganglia—Muscles supplied with Nerves—Vegetable Life of Insects.

THE nervous system has occupied the attention of many naturalists, amongst whom may be specially mentioned Swammerdam (158), Dufour (32), Newport (117), Blanchard (5), Dujardin (33), Brandt (10), and Bütschli (18). In the bee the nervous system consists of a series of enlargements called *ganglia*, or a collection of nerves united by intervening longitudinal double cords. This ganglionic chain extends from the tail end of the body beneath the stomach (frontispiece, *d*), up the middle line of the œsophagus, which it encircles, and reunites above it in the head (*a*). The ganglia are placed in order, one in front of the other, and are also double. The largest is in the head, and is called the brain (Fig. 29, *a*), or supra-œsophageal ganglion. The one under the œsophagus (*f*) is called the sub-œsophageal; whilst the nerve fibres (*g*) which encircle the œsophagus and connect the two, are called the œsophageal collar. The others are termed ganglions, or medullary centres. Bundles of nerve fibres enclosed in a sheath (Fig. 30, B), form the

cords and conduct the nervous force from the ganglions, where it originates, and the impressions derived from without through the medium of the senses to these medullary centres. Each nervous fibril is quite distinct from one extremity to the other, and to this is ascribed the distinctness of sensations, and referring them to the peripheral extremities (Klein, 79).

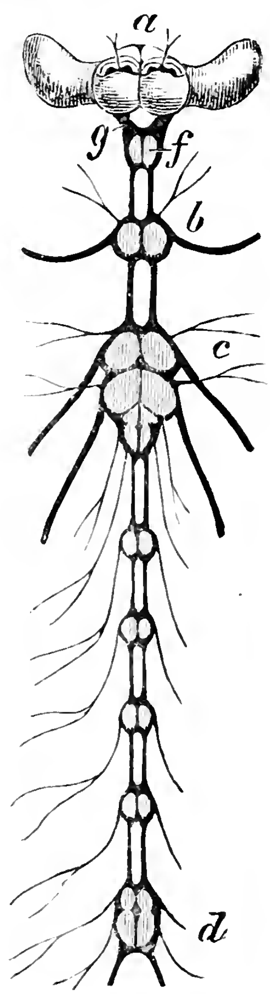


Fig. 29.
Nervous System.

The ganglia are formed principally of cells, called *ganglionic cells* (Fig. 30, A), intimately connected with fibres, and they originate the nerves of sensation and motion, which pass into every part of the body and regulate the animal life of the insect. The fibres and cells are enclosed in a double case (Fig. 30, A, B, and C), the interior lining of which is thick and hard, and coated with a granular layer called the *stratum*, the outer coating being a soft and thin membrane, into which the minute ends of the tracheæ enter.

The cells (Fig. 30, A) are oblong or globular, nucleated, and the largest are found in the abdominal ganglia.

The fibres which connect different parts of the body with the ganglionic chain and brain are called *commissures*, or commissural fibres, and they also communicate with both sides, so as to connect the

impressions on both sides of the body. Other fibres are called *reflex*. As these come in contact with the ganglion cells and return, the impressions produced are reflected back and not conveyed to the other ganglia or the brain.

The ganglionic chain, according to Brandt, by whom it has been specially studied, consists of the supra-œsophageal ganglion (Fig. 29, *a*), which supplies the nerves to the compound eyes (*e*), the ocelli, the antennæ and labrum; the sub-œsophageal (*f*), which

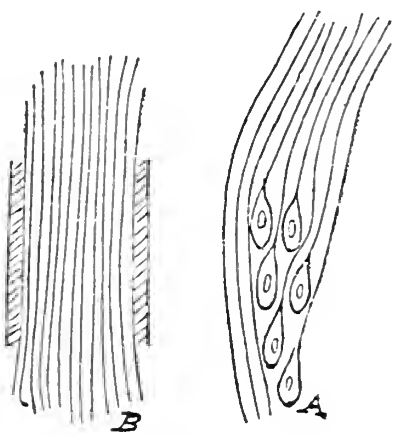
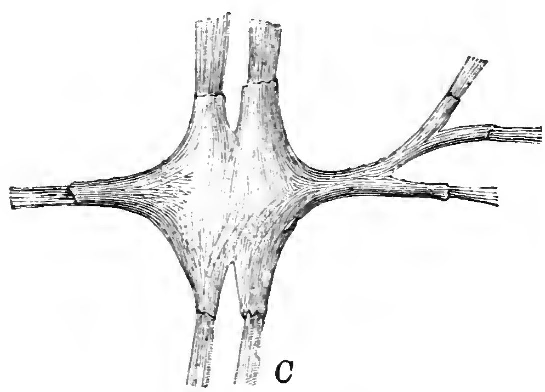


Fig. 30.—Nerves and Ganglionic Cells.



Ganglionic and Nervous Cords.

is connected to it by the collar (*g*), those of the jaws, labium, and the palpi. The first ganglion in the thorax (the pro-thorax, *b*) supplies those of the two anterior legs. The next two (*c*) unite, although they act independently of each other, the upper one sending its nerve fibrils towards the anterior wings and middle legs, whilst the lower one is in connexion with the posterior wings and legs.

The abdominal ganglia, of which there are five in the worker and only four in the drone and queen,

furnish nerves to the muscles in connexion with the wings, and the last one (*d*) branches and supplies those of the armature, genital organs, and sting.

Viallanes (165) and Ranvier (137) have shown that muscles are supplied by nerves which pass into the *sarcolemma*, or outer membrane, and just before doing so they form a ganglionic plexus.*

The vegetative, or organic life—that which is beyond the will, and relates to the digestive functions, for instance—is maintained through the agency of offshoots from the main nervous structures. This is sometimes called the stomato-gastric nerve system, and it is provided with small ganglia, which send their nerve fibres to the organs of digestion, respiration, circulation, and reproduction.

Besides these, Blanchard (7) has described the *sympathetic* nerves, which commence at the œsophageal collar and reunite immediately, having in each segment of the body small triangular ganglia, which send out numerous threads radiating to every part of the body.

* When many are near together, the branches crossing and intercrossing together.

CHAPTER XI.

THE BRAIN.

Instinct—Intelligence—Supra-œsophageal Ganglion—Examination of Brain—Convolutions—Pedunculated Bodies—Relation of Size of Pedunculated Bodies to Intelligence—Comparison of Size of Brain of Various Insects—Brain Smaller in Queens and Drones.

It was supposed that insects incapable of collecting ideas were only actuated by instinct, and that this had its origin equally in each of the ganglia, more especially as it was found that a decapitated insect continued to run and move, and made an endeavour to regain its feet if turned over. Dujardin (33) also mentions several examples which show that voluntary movements can be produced to a certain extent after decapitation. For instance, a large fly (*eristalis tenax*) which had its head cut off and prevented from drying, after between eight and nine hours continued to fulfil its digestive functions, move its wings, its legs, and ovipositor, under the influence of the sun's rays, and when the meta-thorax was touched it immediately brought forward its hind legs to remove the strange object, or to clean and rub its wings; at the same time the tongue was protruded from the separated head to suck the liquid presented to it. All these, however, are purely instinctive movements, actuated by the ganglia, as are those which produce the movements of the sting in a bee or wasp after the abdomen is cut off from the other part of the body.

But besides these there are other actions which can only be attributed to a certain degree of intelligence.

We will now examine that part which Dujardin (33), Brandt (10), and others describe as the seat of intelligence, the supra-œsophageal ganglion, or brain. Fig. 29, *a*, shows the brain in its relation to the ganglionic chain, and Figs. 31 and 32 enlarged views of the brain deprived of its outer coverings, as given by Dujardin in his memoir. He says the brain is so soft and transparent that it is not possible to recognise its structure or trace its form without first

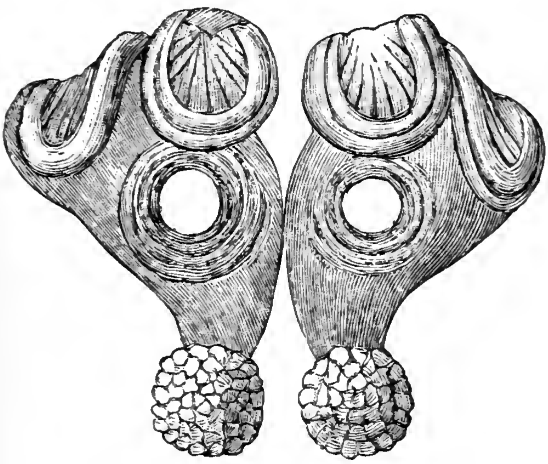


Fig. 31.—Brain Deprived of Outer Covering.

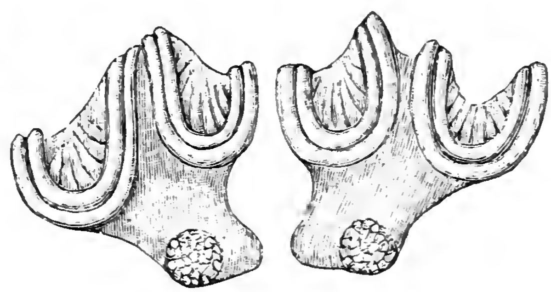


Fig. 32.—View from Top of Fig. 31.

hardening it with alcohol or turpentine, as was done by Swammerdam. But it is necessary to examine the brain in a fresh state to recognise the character of its substance, and that of the coverings which envelop it. When the cranium is removed, we only see first the adipose tissue, the salivary glands, numerous tracheæ, and tracheal sacs, which completely hide the brain. If these are removed, it will be seen that the trachean sac is attached to the brain, which it surrounds

with its double membrane, like an air cushion, which supports and protects this organ. In attempting to remove this, only the outer membrane, which is thicker and striated, like the tracheæ, yields, and there remains attached to the brain the lower and much thinner membrane, which, like the *pia mater*, sends into the interior its small tracheæ, and cannot be removed without tearing the brain itself. Thus exposed and examined under the microscope, the brain substance will be found to consist of transparent globules. If some of the hardening liquid is now poured on, it does not become uniformly white or opaque, but convolutions appear, which are more easily studied after prolonged emersion. Regular convolutions, more or less distinct, first appear near the spot which corresponds to the ocelli. If the pulpy substance which covers these convolutions be removed, we find the inner substance whiter and more solid: this corresponds to the white matter of the brain of vertebrates.

The convolutions form two pairs of discs, turned aside and folded, the projecting parts of which are swelled like a pad, and the central parts marked with radiations. When at last all the surroundings are removed, we end by exposing the bodies to which these convolutions belong and which Dujardin calls pedunculated bodies (*corps pédonculés*). These are symmetrically arranged in the upper parts of the brain, and consist of a short and stout peduncle (stalk) bifurcating downwards, ending in two tubercles, and bearing the convoluted lobes above them. Of the

two tubercles which end the peduncle, the inner one is directed towards the corresponding tubercle of the other pedunculated body, approaching very near to it without, however, quite touching. Its object appears to be to bring the two halves of the brain into relation with each other. The other, directed to the front, and only covered with the double trachean membrane, ends in a granulous surface, and nearly comes in contact with that part of the cranium situated between the antennæ and the ocelli.

It is on this part of the head, Dujardin says, that ants tap each other with their antennæ when they wish to communicate with one another.

From the brain proceed laterally the masses which expand to the compound eyes. The antennæ are provided with nerves, each of which Dujardin found to proceed from a special well-defined lobe, and three short and stout stalks on the upper part are connected with the ocelli. The nerves are placed over the internal discs of the pedunculated bodies, with which they are in communication. The centre one is formed of two separate stalks starting from the lobes on either side, which unite in a common centre, forming the simple eye.

Such, then, says Dujardin, are the parts of the brain which appear to be specially related to the faculty of intelligence. They are more or less covered with the pulpy mass, and it is only of this latter that consists the brain of insects whose faculties are only instinctive.

He further says the more intelligence predominates over instinct the greater becomes the bulk of these

pedunculated bodies, as well as the antennal lobes, in proportion to the size of the brain, as will be seen in passing from the cockchafer (*melolontha*) to the cricket, then to the ichneumon, carpenter bee, or solitary bee, and finally to the social hive bee, where these pedunculated bodies form the one-fifth part of the volume of the brain and the $\frac{1}{940}$th of the volume of the whole body, while in the cockchafer it is less than the thirty-three thousandth. The ant, on the contrary, whose body is much smaller, has a much more fully developed brain, these bodies occupying nearly half the volume of the brain, or $\frac{1}{286}$th part of that of the whole body.

It is generally admitted that the size of the brain is in proportion to the development of intelligence, and Dujardin, who made careful measurements, gives the following sizes:—In the worker bee the brain is $\frac{1}{174}$th of the body; in the ant, $\frac{1}{286}$th; the ichneumon, $\frac{1}{400}$th; the cockchafer, $\frac{1}{3920}$th; the dytiscus (water beetle), $\frac{1}{4200}$th.

Vogel (166) has pointed out that the brain of the queen and drone is smaller, and Girard (48) says that in drones, although they are much larger, more especially in the head, than the workers, the brain is much smaller, not relatively in comparison to the size of the body, but actually. This agrees with the fact that drones are certainly not intelligent, whereas it is impossible to deny this faculty to the others.

CHAPTER XII.

MUSCULAR SYSTEM.

Size of Muscles—Structure—Contraction and Expansion—Muscle Corpuscles—Bundles of Muscular Fibres—Tendons—Muscles of Thorax and Jaw—Power of Traction of Bee—Voluntary and Involuntary Muscular Action.

THE bee has a very powerful muscular system, by which every movement is accomplished. The muscles vary greatly in size, and some are made up of bundles of fibres, whilst others may consist of only a single fibre. They are actuated by the nerves, which cause them to contract or expand.

If examined under the microscope, they appear transversely striped (Fig. 33), and consist of a transparent, homogeneous, elastic outer membrane, the *sarcolemma*, and dark delicate lines stretching across the fibre at regular intervals, so as to sub-divide the space within the sarcolemma into uniform transverse compartments, or discs. These membranes, Klein (79) says, appear fixed to the sarcolemma, so that if the muscle is stretched or contracted its surface is not smooth, but regularly and transversely undulating (Fig. 33, B).

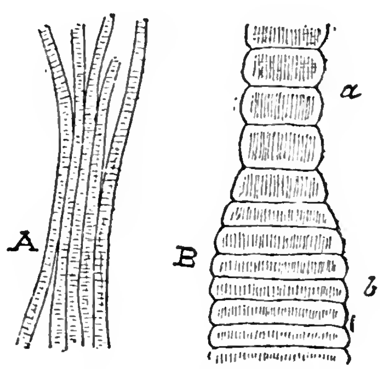


Fig. 33.—Muscles.

Each fibre during contraction becomes shorter and thicker (Fig. 33, B, *b*). In the living, uninjured muscular fibres, a contraction starts at one point and passes over

the whole muscular fibre like a wave—the *contraction wave*—the progress of which is noticeable by the thickening shifting along the fibre, the part behind resuming its previous diameter.

In the central part of the fibres are formed nuclei of protoplasmic corpuscles, called *muscle corpuscles.* These become converted into muscular substance, at the expense of which new fibres are formed, or fibres already formed become thickened.

Muscles are sometimes made up of bundles of fibres (Fig. 33, A), and end in tendons, which vary in length. In colour they are nearly white, but some are pale red.

The number of muscles in a bee is very large and their power very great, the largest muscles being found in the thorax. These are shown in Fig. 21 (*a*, *b*, *c*, and *d*), and it will be seen that they nearly fill up the cavity.

Powerful muscles are also provided for the jaws (Fig. 51, *g*), which are required to knead the wax.

M. Plateau (43), who has studied the power of traction in insects, found that the bee could draw twenty times the weight of its body. The lifting power he found to be equal to the weight of its body. The average weight of a man is 142 lbs., and his power of traction, according to Regnier, is only 124 lbs., or not nearly the weight of his body. This will give an idea of the enormous strength of a bee in proportion to the size of its body.

In bringing different parts of the body into action different muscles are brought into play. Newport (116)

found that besides those that belong to the spiracles, the muscles concerned in the function of respiration included those of each entire segment of the body. Every act of inspiration was of a mixed character, and was partly voluntary and partly involuntary.

Voluntary muscular action is that which depends on the exertion of the will of the insect, and involuntary that which is independent of such will.

Every act of expiration is more of an involuntary character, and may be regarded simply as a disposition in the muscles concerned to regain their previous condition, which is intermediate between contraction and relaxation, and takes place independently of the will of the insect (Newport).

For instance, the muscular actions of the dorsal vessel and the stomach are involuntary, whilst those of the jaws and wings are voluntary.

It would be impossible, within the limits of this work, to describe all the muscles, and we must content ourselves with saying that there is not a movement in the body of the bee but is actuated by them.

CHAPTER XIII.

STING STRUCTURE.

Analogy of Sting to Ovipositor—Sheath, Darts, Pouch, Barbs—Groove—Compound Levers—Lancets Tubular—Guide Bars—Valves—Poison Sac—Alternate Movement of Lancets—Lever Muscles—Poison Gland—Pump-like Action—Formic Acid—Oil Gland—Lubrication of Sting—Curved Sting of Queen.

THERE are few bee-keepers who have not at one time or another felt that bees have stings, and that they are able with them to cause pain. The sting apparatus is provided as a weapon, and has been pointed out by Dewitz (30), Vogel (166), and others, to be anatomically analogous to the ovipositor of insects, with this difference, that whereas the ovipositor is an apparatus of the female for depositing eggs, in those insects provided with a sting, the female organs are so differentiated, aborted, or completely suppressed, as to render fertilisation impossible. Most writers on the honey bee have described the sting, amongst whom may be mentioned Burmeister (17), Westwood (169), Duthiers (36), and others; but it is to J. D. Hyatt (71) in 1878, that we are indebted for a complete anatomical investigation and description of this organ. He says the difference between a sting and an ovipositor is more a difference of function than of structure.

By referring to Fig. 34, it will be seen that the sting consists of a dark brown, horny, chitinous piece commonly called the sheath, A (because it was supposed to

enclose, like a scabbard, the two darts, or lancets), which is cleft along its under surface, and terminates in an obtuse, but extremely thin, cutting edge. Fig. 35, B,

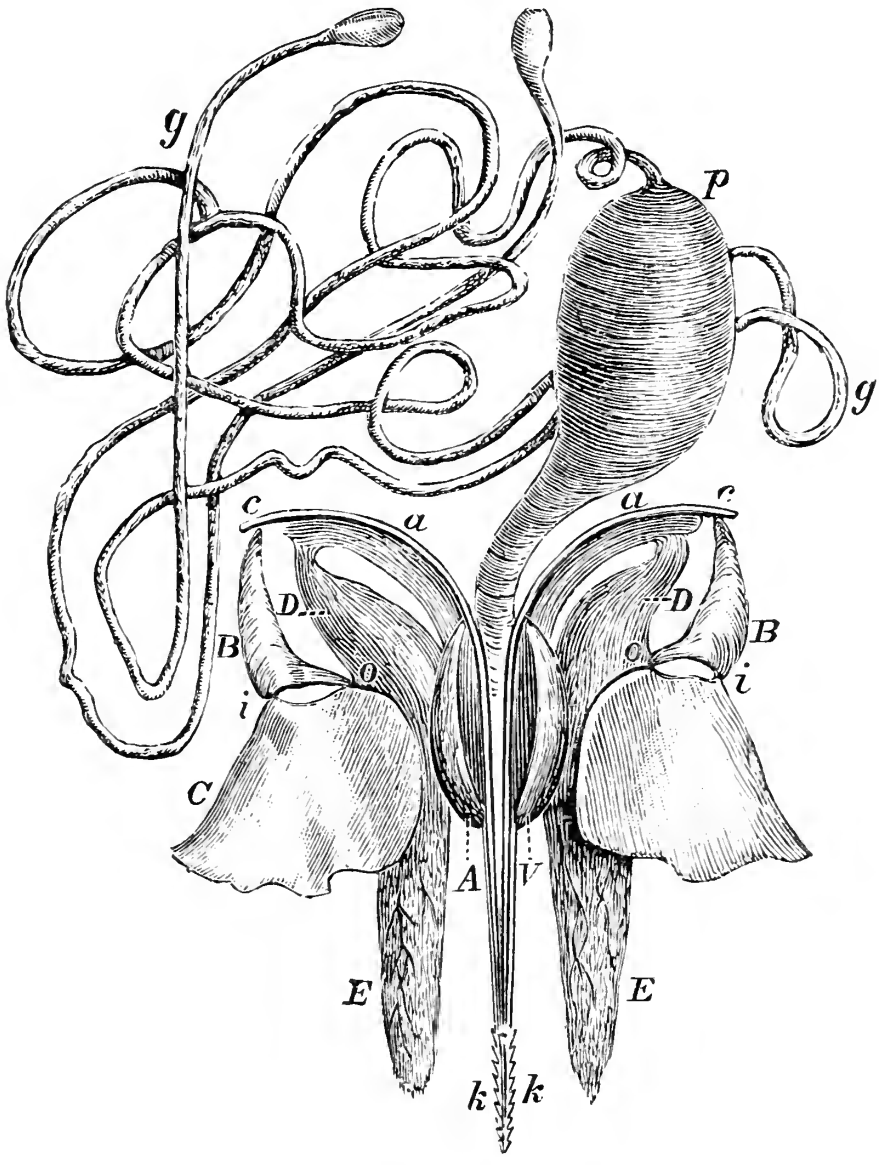


Fig. 34.

shows the upper part (A) as an enlarged pouch, contracting at the point (*c*), and diminishing gradually to the extremity, near which are found teeth, seen enlarged at Fig. 35, H, *b*. The sheath is double throughout its whole extent, the interior space being filled with blood. The

exterior and interior walls are united at their edges, and in the pouch-like portion of the sheath are nearly in juxtaposition, forming the oblong valve chamber (A). A cross-section is given in Fig. 35, C, showing the space (*n*) between the walls. At the point (Fig. 35, B, *c*) where the contraction is seen, the space begins to alter its form (Fig. 35, D), and continues to diminish (E), until at the apex the two walls unite and form a solid cutting edge (H).

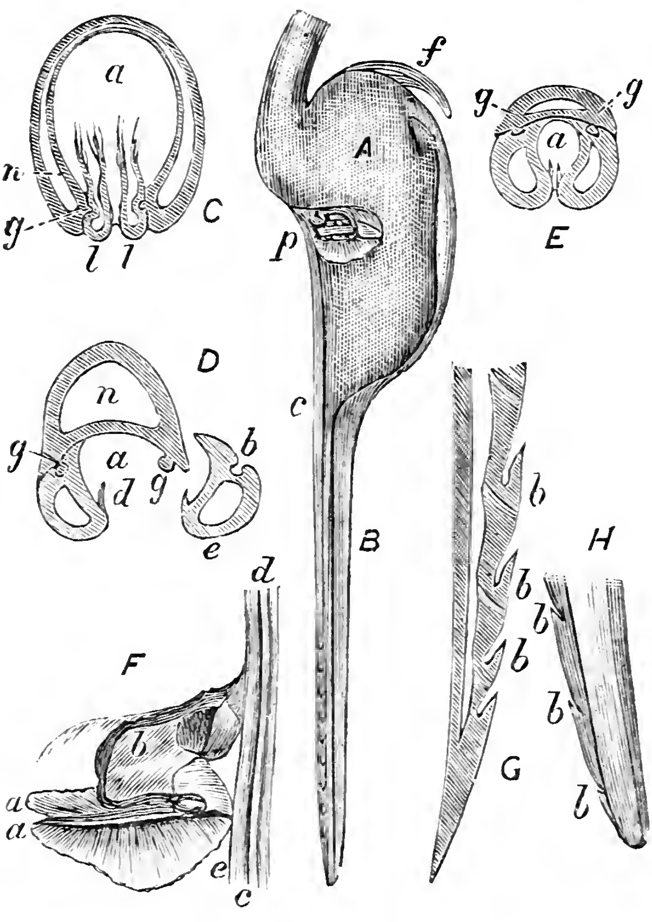


Fig. 35.

It will be seen that the space *n* (Fig. 35, C) has no connexion with *a*, so that the poison injected into the base of the sheath follows the channel *a* (Fig. 35, D and E) between the lancets. Near the upper end of the sheath are two flexible arms, which curve in arcs of a circle, and carry the guides on which the lancets slide. A cleft commences at the lower part of the valve chamber, and taking the form of a shallow groove, continues to the end of the sheath. The lancets lie in contact with this groove, with their barbed edges (*k k*, Fig. 34), extending outwards over

its sides, and following the curve extend the whole length from *k* (Fig. 34) to *c*, where they are attached to the triangular pieces (B B) of the compound levers composed of the pieces B and C. Along the sheath are seen two **T**-shaped rails (Fig. 35, C, D, E, *g*), or guides, which exactly fit into grooves of similar form in the lancets, and along which they slide. The lancets have a fine cutting edge, and are provided along their outer edges towards the points with ten deep retrorse barbs (Fig. 35, G, *b b b*). The lancets are capable of being protruded beyond the sheath, so as to increase the depth of the wound made by that instrument.

The extent to which the lancets may be projected is limited by the stop at *p* (Fig. 35, B), while the sheath can enter the flesh, and is assisted in doing so by the teeth (*b b*, H), until it is stopped at the point *c* by the enlarged pouch A. From *p* (Fig. 35, B) along to their points the lancets are tubular, taking the form *e* (Fig. 35, D), lying side by side, and forming a circular channel *a* (Fig. 35, D and E) between them, through which the poison is injected.

A small canal extends from the central cavity in the lancets to the fine teeth (Fig. 35, G, *b b b*), so that the poison not only passes down the circular channel, and out between the points of sting, but also through the canal in the lancets and out between the barbs.

The appendage *p* (Fig. 35, B), of which an enlarged view is given at Fig. 35, F, acts as a piston to force and a valve to regulate the flow of poison through the channel between the lancets, as may be better seen in Fig. 35, C,

which is a transverse section through the point at which the two pieces forming this valve are attached, and shows the opening between them to the interior cavity of the lancets, through which the poison enters the moment this valve closes the channel between the lancets by striking into the angles of the sheath at *c* (Fig. 35, B). The valves consist of two semicircular pieces (F, *a*, *e*), fixed by their loose edges to the lancets (*c d*), the straight sides being uppermost, thick and chitinous. These pieces are braced together by a heavy curved plate (*b*), extending from them to its attachment with the lancet.

The poison, which is contained in the sac (Fig. 34, *p*), and is in the worker a clear liquid, pours its contents into the large chamber of the sheath, and by the action of the valves is forced into the wound through the canals in the lancets, and out at the openings between the barbs, with considerable force.

Carlet (20) found that the two lancets of the sting may move simultaneously or alternately; but in either case the valves, which act as a piston, can at each stroke force out a drop of poison, and at the same time a fresh afflux of liquid is produced at the base. The apparatus acts like a syringe, and by its two pistons, *à parachute*, it drives out by the canula the liquid which it draws in at its base.

The lever mechanism which enables the bee to drive its sting right up to the bulbous enlargement with such force will be understood by reference to Fig. 34. The darts are attached at *c* to the levers B. The levers, C and D, are furnished with broad muscles,

which extend in groups forward to the lower segments of the abdomen, the plate D being fixed by a ligament connected with the curved arm above.

By the contraction of the muscles the levers turn on the points O, and the curved arm being straightened and shortened, the sheath and attached lancets are projected. By a contraction of the muscles of C, turning as it does on *o*, its only point of attachment to D, the point *i* is raised, and the lever B, which turns on O, is tilted over, and causes the lancet articulated to its movable arm at *c* to slide along the groove towards *a*, and thus project its point into the wound beyond.

Hyatt (71) says that by allowing a bee to sting a soft piece of leather an excellent opportunity is afforded for studying certain parts of the action and mechanism, for the whole apparatus, including the poison gland, will be beautifully dissected, the bee not appearing to be seriously injured by the loss. These movements, which can be easily seen, are of course reflex, because they continue for some time after the organ has been removed from the body of the bee, and bee-keepers will now understand why a bee apparently dead for some hours is able to sting.

The venomous effect of a wound made by a sting is entirely due to the poison introduced by it, or we could not feel the pain we do by the mere thrusting in of the dart $\frac{1}{500}$th of an inch in diameter to a depth of $\frac{1}{50}$th of an inch.

The poison is secreted from the blood in the cellular glands (*g*, Fig. 34) attached to the poison sac (*p*), which commence in a single tube bifurcating, and

continue for a considerable distance, winding amongst the malpighian tubes and outside the chyle stomach like two white tubular threads which have their extremities enlarged. These enlargements contain the secreting glands. They produce the formic acid of which the poison consists, and Girard (48) says it is possibly associated with some other toxic agents. For this reason ammonia is recommended as a curative agent, as it neutralises the formic acid. Although this acid acts as a poison if one bee stings another, Dennler has shown that a certain quantity can be taken into the bee's stomach, as he found, if mixed with food in his remedy for foul brood, it has no ill effects.

Girard (48) says that the poison is driven from the sac by the muscles which project the sting, and at the same time press on the poison sac, expelling the venom. Carlet (20) has more recently found that the poison sac has not a muscular investment, that it is not contractile, and cannot in any way act on the contents, which are therefore pumped out in the manner we have already described.

Attached to the stinging apparatus are two palpi, or feelers (Fig. 34, E E). That they serve this purpose is evident, because they are provided with delicate feeling hairs, and are always protruded in advance of a thrust made by the sting, to ascertain the most vulnerable point of attack. The poison of a bee on drying cracks, and appears like Fig. 36, while in it will be found numbers of oil globules. Leuckart found this oil was secreted by a special gland (frontispiece, *u*), and both he and Vogel (166) state that

this oil, which has a strong smell, is used to lubricate the sting, and it thus allows the mechanism to work freely.

Carlet, however, states that the venomous apparatus is always formed by two distinct systems of glands, one having a secretion strongly acid, and the other feebly alkaline. The combined liquid of the two systems is always acid, and as he found that the inoculation of the product of either of the glands does not result in death, it is clear, he says, that the union of the acid and alkaline secretions is necessary for the venom to have any fatal effects.

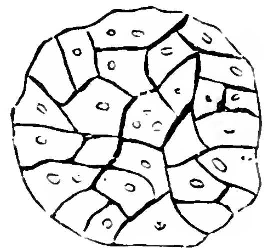


Fig. 36.
Poison and Oil Globules.

The sting of the queen is in structure similar, but is curved, and is of greater length, and has from three to five very small barbs. Dewitz (30), Vogel (166), and others, have pointed out that it is not only analogous to an ovipositor, but is actually used for this purpose by the queen bee (see also Grimshaw, *B. B.J.* 1888, p. 514).

The sting of a queen is used against a rival, and most writers are agreed that she does not usually sting a human being, although we have ourselves on one occasion had experience that she is able to do so, and that she was also able to extract the sting much more easily than a worker. This was done by working round and giving the sting a spiral motion, similar to drawing a corkscrew out of a cork. If time is allowed a worker can withdraw her sting in the same way, although generally she loses besides the sting the

poison sac and glands and the lower portion of the abdomen in her haste to get away.

The queen is not eager to use her sting, probably owing to a consciousness of the importance of her life to the community.

The poison sac of the queen contains only a thick milky substance, and is very different to the fluid contents of the worker's poison sac. Drones are not provided with stings at all.

CHAPTER XIV.

ORGANS OF SOUND.

Variations of Sound—Voice—Tones Produced—Wing-beats—Buzzing and Humming—Epiglottis—Stigmatic Vestibule—Vocal Membrane—Obturator Tendon and Muscle—Stirrup—Description of Sounds.

EVERY bee-keeper knows that bees emit certain sounds, not only when they fly, but also at other times. Who has not noticed the particular music produced at swarming, or the whizz of an irritated bee when attempting to sting?

The variation the music of the bee is susceptible of in the expression of pleasure, fear, or anger, did not escape the attention of the great John Hunter (69).

'Hive bees,' he says, 'may be said to have a voice. They are certainly capable of forming several sounds. They give a sound when flying which they can vary according to circumstances. One accustomed to bees can immediately tell when a bee makes an attack by the sound, which is a very different noise from that of the wings when coming home of a fine evening loaded with farina or honey; it is then a soft, contented noise They may also be seen at the door of their hive, with the belly rather raised, and moving their wings, making a noise.'

The drones can be recognised from the workers or queens by the difference of the sounds produced.

That sounds are as varied as they are numerous will be admited; we will therefore endeavour to show how they are produced.

The voice organs of insects have been studied by Swammerdam (158), Réaumur (139), Hunter (69), Charbrier, and Burmeister (17); but it is principally to Landois (88) and Marey (107), who carried out elaborate experiments, that we are most indebted for what we know.

Charbrier, Burmeister, and Landois recognise three tones produced by bees: the first by the vibration of the wings; the second, much sharper, by the vibrations of the abdominal rings; and the third, the most acute and intense, by the action of a true vocal apparatus placed in the stigmatic orifice.

Landois (88) described the tones due to the wing-beats. The wings produce a tone which depends upon the number of vibrations, varying from one individual to another according to the size of the wing. Landois found this wing-tone in the bee in vigorous flight to be 440 vibrations, up to *a* in the treble clef, and dropping to *e*, or 330 vibrations, when fatigued. The queen and drone produce different tones, owing to their wings being longer.

Marey (107), in 1868, measured the wing-beats by the graphic method described on page 44, and found 190, but such experiments are uncertain, owing to their great difficulty. When the vibrations are reduced to 190 the tone produced is over an octave lower than the note *a*.

The noise is not produced by the wings only, as a simple experiment of Girard (48) proves this. If one of the large humble bees, such as *Bombus ter-*

restris, *hortorum*, or *lapidarius*, be shut up in a box, a loud and violent humming, the sign of anger or fear, will be heard, even if the wings are only producing a slight tremulous motion.

The wings are only one cause of sound, and produce the buzzing, but the humming is due to an apparatus connected with the spiracles and tracheæ.

The spiracles, specially studied and described by Krancher (84) in this connexion, of which Fig. 37 is a representation, showing the apparatus called by Straus-Durckheim (157) *epiglottis* (epiglotte), have their mechanism hidden beneath the outer skin. The opening to the spiracle is seen at *g*, and communicates with the outside, being covered with hairs to prevent the access of dust. This leads to an enlargement at the commencement of the trachea and immediately behind the spiracles, called the *stigmatic vestibule*, which acts as a sounding box, and plays an important part in increasing sound. A folded membrane (*f*), called the *vocal membrane*, and forming the lips, or curtains, more or less plaited and fringed, is placed between the edges of the spiracle (*g*) and the sounding box, which, vibrated by the air, produces a different sound according to its tension. At the end of this enlargement there is an apparatus for closing the

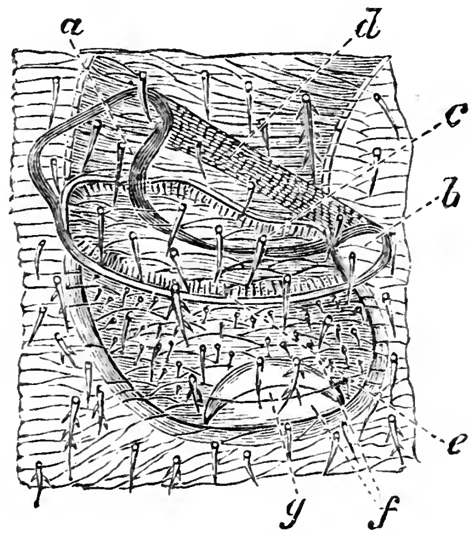


Fig. 37.—Spiracle.

trachea, and this comes into action on the contraction of the muscle actuating the apparatus, during respiration as well as in the production of sounds. By the closing of the tracheæ the passage of air from these to the outside is entirely shut off, and during expiration the stream of air to the outside can be regulated and made to pass over the edges of the folded membrane, and the sounds are produced in a manner similar to that of a bugler, who produces different sounds by blowing through his lips into the mouthpiece of his instrument.

The mechanism by which the closing of the trachea is effected consists of a double lever formed of two unequal cones (*a* and *b*), connected by a transverse muscle, and placed at the two extremities of the *obturator tendon* (*c*). This muscle, called *obturator muscle*, seen stretched from *a* to *b*, in contracting, causes it, as well as the tendon, to act on the *stirrup* (*e*), which closes the trachea at the will of the insect.

Landois (88) found that by stopping the openings of the spiracles with wax, humming ceases, or becomes so feeble that it is hardly perceptible. The reason is easily explained if we bear in mind the structure of the spiracles. He considers the spiracular notes to be due principally to the large meta-thoracic spiracles, and that the abdominal ones may also assist in their production.

Baron von Berlepsch (3), Pollmann (134), and others have described the various sounds produced. Stahala has given to the sounds different meanings. For instance, he says that, if in winter one taps the

hive and a loud 'Huumm' is heard, it is a sign that the bees have their queen and sufficient food. The loud 'Dzi-dzi' is heard when both stores and bees are dwindling. The loud 'Dziiiiii' will be heard when they are too cold. 'Huuum' is produced by queenless stocks both in summer and winter. A loud 'Wuh-wuh-wuh' is only heard when breeding is going on, but never when the hive is queenless, or has an unfertilised queen. When water is being collected they produce a loud 'Usiiir,' and young bees playing outside the hive utter a loud 'Shu-u-a,' but as a swarm leaves the hive 'Shiusi' is produced, the normal sound of a swarm being 'Ssssss.' 'Brr-brr-brr' is heard when drones are being expelled. And the 'Tu-tu-tu' is known to every bee-keeper as the sound produced by the just-hatched young queen, which is answered by 'Qua-qua-qua' of those queens still enclosed in their cells. Besides these there are some dozen other sounds produced, differing both in tone and in intensity.

CHAPTER XV.

SMELLING, HEARING, AND UNKNOWN ORGANS.

Antennæ, organs of Sense—Touch—Structure of Antennæ—Oval Depressions and Circular Hollows—Tactile Hairs—Conoid Hairs—Smell Hollows of Schiemenz—Highly Developed in Drone—Auditory Cavities of Hicks—Taste Organs on Labrum—Unknown Organs—Labial Palpi—Taste Hollows on Tongue.

THE existence in insects of the sense of smell has never been denied. Bee-keepers have constant evidence that bees possess this sense very highly developed. We have seen that bees produce various sounds; it is consequently reasonable to assume they can also hear.

The question frequently discussed and which has puzzled our leading scientists is: Where are to be found in insects the organs of smell and hearing? There is perhaps no subject which has had more investigators, and the antennæ have been anatomically examined and described, and the conclusion has been arrived at that, from their structure, they are certainly organs of sense. This much is determined with certainty; still, it remains to decide what is the character of the sensory function performed—is it that of smell, hearing, or touch, or of any or all of these combined?

That they are organs of touch is decided beyond doubt, but whether with this sense there is combined that of hearing or smell, or whether they convey

external impressions to nervous centres in a manner inappreciable by us, is still an open question, for however carefully they have been examined and compared with the sensory organs known in other animals, no physiologist has yet been able to pronounce definitely with regard to their function.

Besides Burmeister (17), Newport (118), and others who have occupied themselves with the subject, the antennæ are considered as organs of smell by Lefebvre (92), Erichson (40), Perris (125), Hauser (61), Schiemenz (144), and Briant (11); whilst Braxton Hicks (64), Graber (54, 55), Mayer (108), Berlepsch (3), and Vogel (166), consider them organs of hearing.

Schiemenz (144) has examined the antennæ most carefully and described them minutely. The illustrations (Fig. 38) are taken from his work. He says each antenna carries six different structures, which in their disposition show considerable regularity. If we examine the antennæ we shall find the first three joints and the terminal joints of the flagellum (Fig. 8, *b*) differ from each other and from the remaining eight joints. In these the back and front sides are unlike, the back being covered only with curved hairs, and on the front side there are in addition amongst them a number of oval depressions, first anatomically described by Erichson, and here and there larger straight hairs. Besides, there are, near to the lower part of the outside of these joints, patches of small circular hollows.

The hairs on the scape and those found distributed

here and there on the back of the other joints are like B (Fig. 38), and have the same structure as many of those on other parts of the body. The other hairs on the back of the flagellum are similar to C. By referring to A (Fig. 38), which gives a longitudinal section

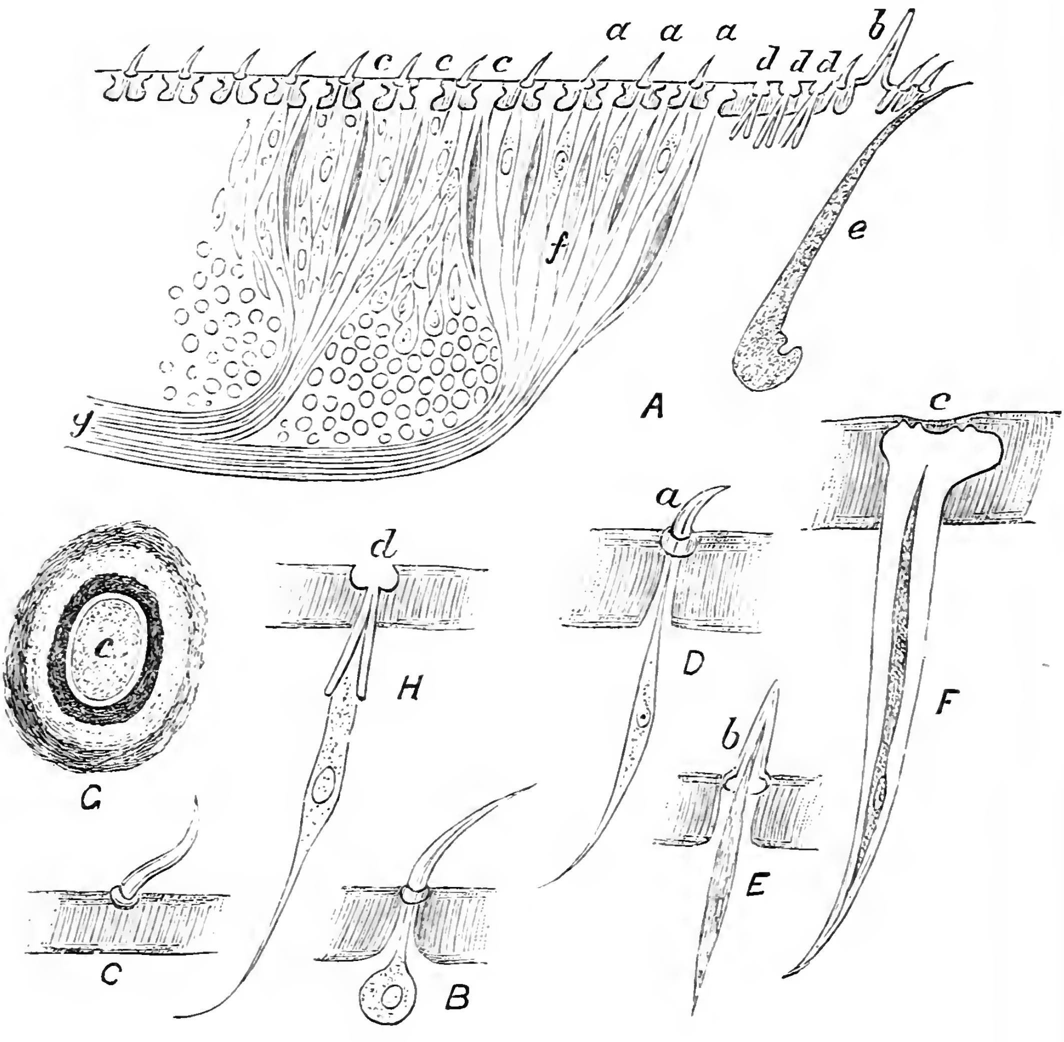


Fig. 38.—Structure of Antennæ.

through one of the joints, a number of short hairs (*a*) will be seen. These are set loosely into the framework of the antennæ by a ring and are in connexion with a nucleated end cell (D). These are the tactile hairs of Hauser, and from their number make the

antennæ most sensitive touch organs. They are mostly found on the front side. Besides these there are conoid hairs (Tastkegel—*b*, A), which are situated nearly at the end of each joint. They are hollow and have a nerve fibre (E, *b*), Schiemenz considering them modified bristles which act as feelers, more especially as they are found in greatest abundance at the extremities of the antennæ.

Between the tactile hairs in the antennæ of the worker are found cavities covered by a thin layer, which on the outside surface show consecutive oval rings. Fig. 38, F, shows an enlarged section of one of these hollows, and the appearance of rings is produced by the difference in thickness of the layer of chitine. When looking down upon these depressions they have the appearance of G. These hollows are placed at an angle, and into the cavity below (*c*, F), passes a nerve end cell. These Schiemenz considers smell hollows, and he finds little difference in their numbers in a worker and queen, but says between these and the drone there is a great difference. Whereas in the queen and worker they are larger and further apart, with tactile hairs situated between them, those in the drone are crowded so closely together that there remains hardly any room for the feeling hairs, which are in consequence only found singly here and there, and only appear in greater numbers on the terminal joint. They are besides much smaller, so that the surface covered by them contains a very much larger number. Schiemenz says this is as might be expected, if these are considered as organs of smell, for

males who have to seek the females have the antennæ much more fully developed.

Hauser (61) says that it can be taken as an invariable rule that the males have the antennæ much more developed than the females, when these from their habit of life live in hidden and retired places.

We have still to describe the small hollows mentioned above, situated in patches of ten or more at the lower part of the joints. In Fig. 38 (A, *d d d*) are seen three of these in section, and at H one of them enlarged. The opening leads into a large cavity (*d*, H), from the bottom of which extends a widening canal, and inside from the base of this rises a chitinous cone, which is gradually reduced to a fine point below the opening. Into this also extends a nucleated nerve end cell. Schiemenz found a larger number of these cavities in the drone than in either the queen or worker. Schiemenz and Hauser consider them as organs of smell, whilst Hicks and Graber suppose them to be auditory in function. Hicks calculated that there were 20,000 pits, and 200 of these cones in each antenna.

Dr. Wolff (170), however, considers the olfactory organ as situated in quite a different position, namely, on the soft palatine skin of the labrum, within the mouth. It has a number of sensory pits or cups (Fig. 39, *b*), provided with delicate papillæ, from which olfactory nerves proceed. Fig. 40 shows three of these cups (*b*) enlarged, each having a central hair (*a*), a chitinous ring, and a double ganglionic swelling (*c*), terminating in a nerve fibre.

Vogel (166) and Kraepelin (81) support this view, considering this an olfactory organ, and the hollows on the antennæ as auditory; but we think that the view

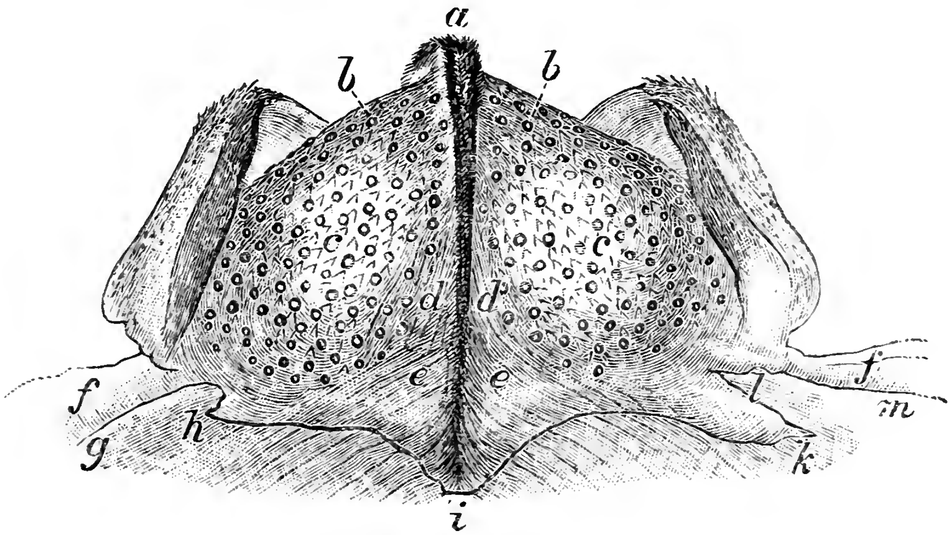


Fig. 39.—Taste Organ on Labrum.

taken by Sir J. Lubbock (102) and others, that they are more likely to be organs of taste than of smell, is the more rational one.

The nerves from the different hairs and hollows on the antennæ collect in bundles (Fig. 38, A, *g*) and convey the impressions from outside to the nerve centres.

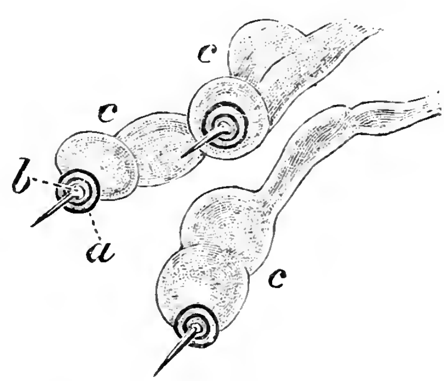


Fig. 40.—Wolff's Cups.

Whether the antennæ are to be considered as organs of smell or hearing is still undecided, although we think the weight of evidence so far is in favour of their being considered olfactory.

Porter (135) thinks, from his experiments, that the antennæ are not the organs of any of the so-called

five senses, or any combination of these, and is inclined to adopt the opinion of Trouvelot that they are the organs of some sense not possessed by us. That this is possible is admitted by most scientists, and Lubbock (101) says:—

'Indeed, it is not impossible that insects may possess senses, or sensations, of which we can no more form an idea than we should have been able to conceive red or green if the human race were blind. The human ear is sensitive to vibrations reaching at the outside to 38,000 in a second. The sensation of red is produced when 470 millions of millions of vibrations enter the eye in a similar time; but between these two numbers vibrations produce on us only the sensation of heat; we have no special organs of sense adapted to them. There is, however, no reason in the nature of things why this should be the case with other animals; and the problematical organs possessed by many of the lower forms may have relation to sensations which we do not perceive.'

There are quite a number of organs still not investigated, and whose functions are not determined.

Amongst these is an organ described by M. Nassanoff (172). In dissecting the abdomen of the bee, he found on the sixth ring a small canal (Fig. 41, A), which passes along the edge of the dorsal half of the ring, and is covered above by the edge of the fifth ring. He calls to mind the fact that when bees are irritated they often raise their abdomen, turning the tips downwards in such a manner that the last two rings spread apart, and show a white stripe, which separates them. It is exactly upon the posterior part

of this stripe that the canal is found opening towards the space between the rings. At the bottom of this canal a large number of small glands open, each one

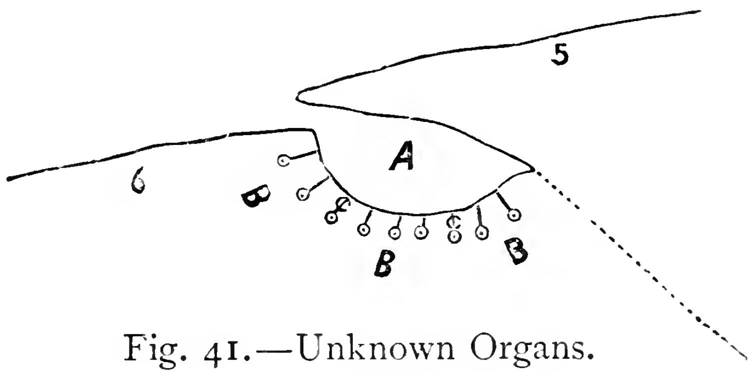


Fig. 41.—Unknown Organs.

of which has an oval cell (B), with a well-defined globule. From each cell a fine duct starts outwards and extends to the bottom of the canal. The walls of these ducts he found to be chitinous, the same as the outer covering. To these glands he ascribes an excretory function, and Zoubareff (172) alludes to the drops of liquid bees let fall when they are on the wing, and says that as honey stored in the cells contains very much less water than the liquid the bees gather, he thinks, probably, it is this excess that is collected and thrown off by these glands.

Dr. Braxton Hicks has also pointed out patches of circular hollows at the base of the labium, and others situated close to the origin of the palpi, and also those amongst the hairs at the apex of the labial palpi (Fig. 42, A, *c*), but has not determined their function, suggesting that they might be supplemental organs of taste.

Wolff (170) also describes small hollows situated

near the root of the tongue, which he considers as taste organs (Fig. 43). There are about twenty-five of these hollows on each side, and beneath each is also a ganglionic swelling connecting it with a nerve

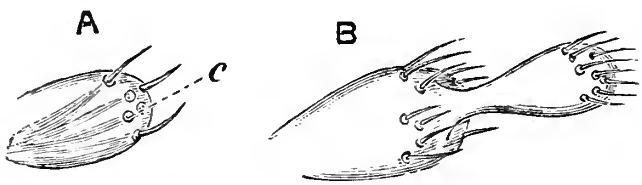


Fig. 42.—Sensory Organs on Palpi.

end. Besides these there are also the taste hollows on the tongue alluded to at page 26 (Fig. 12, *p p*).

The apparatus of sensibility which we have described is not composed only of the different parts of the nervous system already pointed out: the nerves,

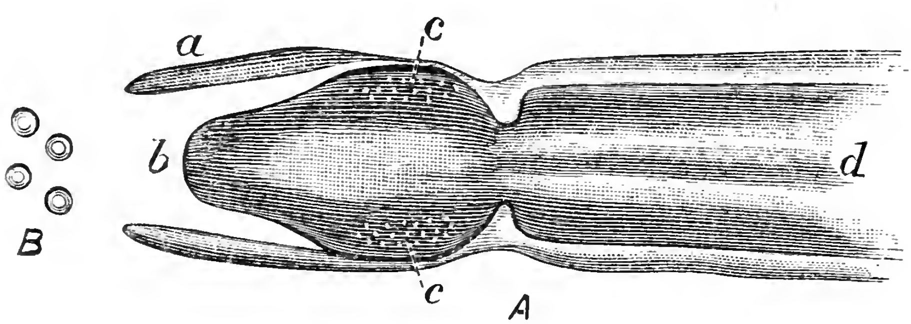


Fig. 43.—Taste Organs on Tongue.

furnished with power of transmitting to the brain sensations from without, terminate in positive instruments destined to collect the impression, and to prepare it to assume its action. These are therefore called the organs of the senses, and it is through the intermedium of them that the sensations reach the insect, but they are not indispensable for the exercise of all the faculties.

The tactile sensibility is called into play where nerves exist, and tactile hairs are found on different parts of the body, but it is only by the special senses, namely, by taste, smell, hearing, and sight, that this intermediate organ between the nerve and the external world is necessary. The first three have had attention in this chapter; there still remains, therefore, the organ of sight, which we shall describe in the next chapter.

CHAPTER XVI.

EYES AND SIGHT.

Compound Eye — Cornea — Hexagonal Facets — Ommateum — Crystaline Cone — Rhabdia — Retinulæ — Pigment — Basilar Membrane — Opticon, Epiopticon, and Periopticon — Crossing Nerve Fibrils — Number of Facets — Drones' Eyes Larger — Mosaic Vision — Microscopic Experiment — Stemmata, or Ocelli — Distance Seen — Use of Ocelli — Drones with White Eyes.

THE organs of sight consist of a pair of large compound eyes (Fig. 6, *d*) and the simple eyes, or ocelli (Fig. 6, *i*).

If one of the compound eyes be examined under the microscope, we shall find the outer layer divided into a number of hexagonal facets, which are convex, and form the *cornea*. Between most of the facets are found long straight hairs (Fig. 44, *h*), which act as protection to the eye similar to eye-lashes, and they are also sensory.

Every eye of insects is made up of several parts, each set of parts being called by Carrière (21) and Hickson (67) *ommateum*, or *ommatidium*.

Dr. Grenacher (57), who has described the compound eye of the bee in his admirable monograph, gives illustrations, which we have copied in Figs. 45 and 46, and which, with Fig. 44, taken from Lowne (99, 100), will assist us in understanding better the structure of this organ.

Each facet of the cornea (Figs. 44 and 45, *c*) is a

bi-convex lens, or *corneule*, chitinous and perfectly transparent. Beneath each is placed the crystalline cone (*c c*) ensheathed by pigment cells. The crystalline cone has been carefully studied by Claparède

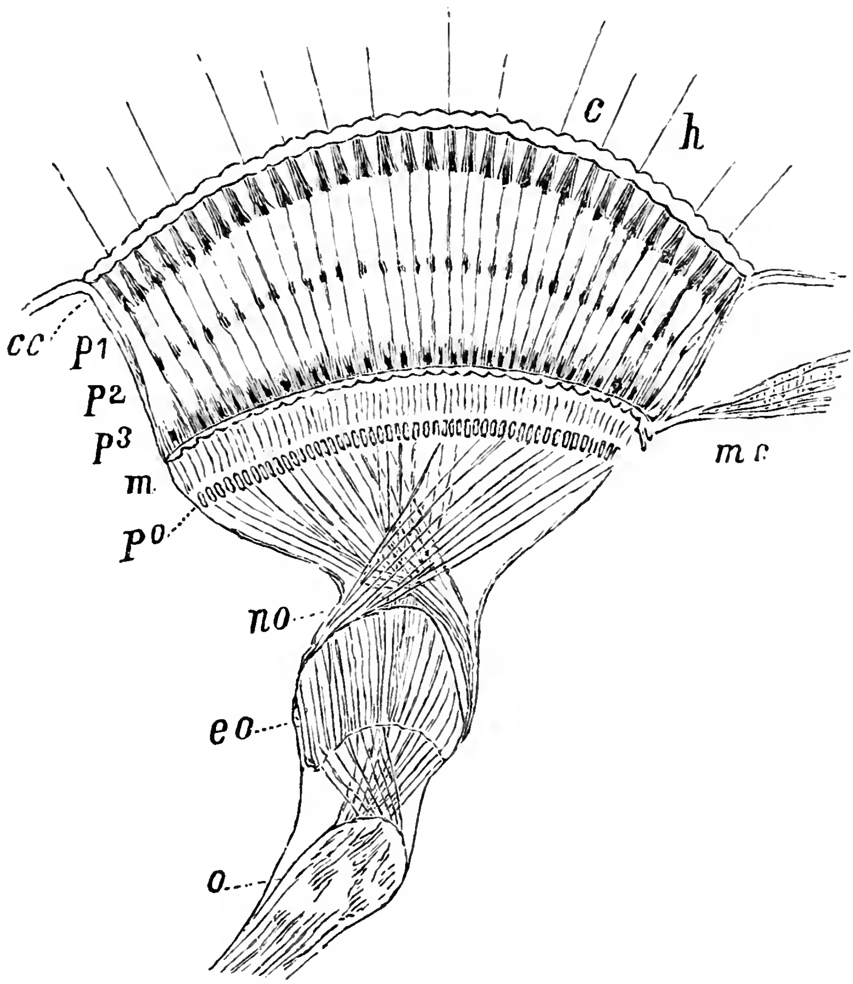


Fig. 44.—Longitudinal Section through Compound Eye.

(25), and found by him to consist of from four to sixteen original, but completely combined segments, secreted by cells which lie immediately behind each facet, but of which, when the eye is completely developed, only the nuclei (Fig. 45, *n*) (known as Semper's nuclei) finally remain.

Grenacher (57) divides the compound eyes of

insects into three types, and to those having true crystalline cones like the eyes of the bee he has given the name of *eucone* eyes.

Below the cones come the *rhabdia* (Figs. 45, 46, *r b*), which consist of delicate chitinous rods, having round them and united together throughout their length the eight *retinulæ*, *r*, about which are placed pigment cells, which have a greater density at the upper, middle, and lower portions of the rods (Fig. 44, p^1 p^2 p^3). The rods perforate the basilar membrane (Fig. 44, *m*), between which and the brain there are three ganglionic swellings, which Dr. Hickson (67) has called *opticon* (*o*), *epiopticon* (*e o*), and *periopticon* (*p o*.) The periopticon is situated immediately behind the basilar membrane, and is separated from the epiopticon by a bundle of long

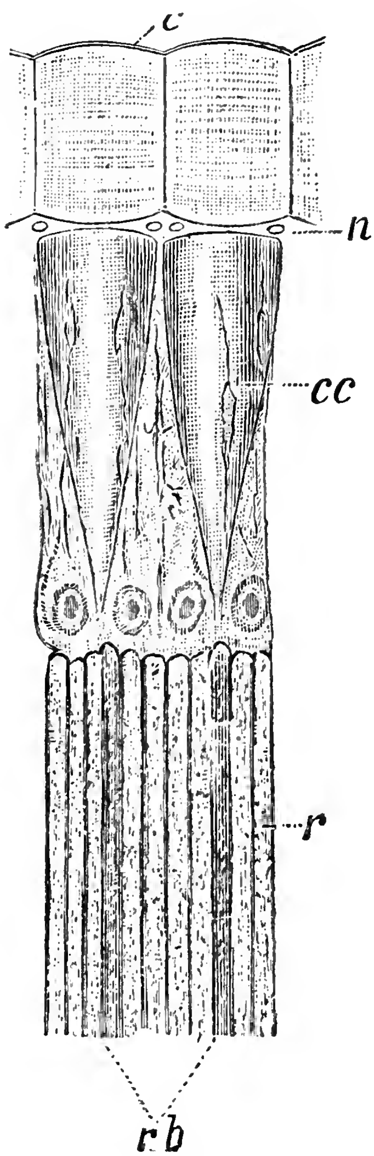


Fig. 45.—Longitudinal Section of Part of Eye.

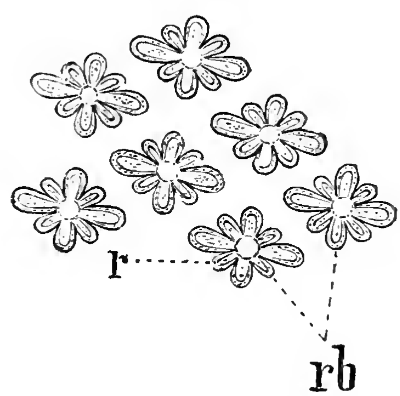


Fig. 46.—Cross Section of Fig. 45 through *r*.

optic nerve fibrils, which cross one another, as seen at *n o* (Fig. 44). This second ganglionic swelling is separated from the next, the opticon, by a tract of nerve fibrils, which partially decussate, and a few scattered nerve cells. Beyond this is the cerebral ganglion, separated from the opticon by a narrow constriction, which Berger (2) has pointed out to be the homologue of the optic nerve of the other arthropoda. The three optic ganglia, together with the cerebral ganglia, are surrounded by a sheath of very densely packed nerve cells, called by Leydig (95) *Punktsubstanz*, and found by him to consist of densely packed nucleated cells, connected together and having amongst them fine nerve fibrils. The cells are not so densely packed in a developing bee as they are in the adult, and are therefore more easily distinguished.

The opticon consists of a very fine granular matrix, traversed throughout by a fine meshwork of minute fibrils, which tissue Hickson calls *neurospongium*. The periopticon is composed of a number of cylindrical masses of neurospongium, arranged side by side, into which the nerve fibrils coming from the epiopticon, and divided into two or three fibrils, enter. These again sub-divide, and form the fibrillar meshwork of the neurospongium. The nerve fibrils from these elements join the numerous nerve cells, which in turn furnish the fibrils which pass through the basilar membrane to supply the retinulæ, as shown by Grenacher. Numerous tracheæ are found running more or less parallel with the basilar membrane, and which spring from the tracheal trunks situated behind

the eyes, and also supply the tracheal vesicles, which are found between the ommatidia.

We have seen that the compound eyes really consist of a number of separate eyes, united together and directed to different points (Fig. 44) of the horizon, and thus permit the insect to have a wider range of vision in all directions than would have been possible with a simple eye.

The number of facets in the compound eyes of bees differs greatly, and in the worker the lowest is given as 3500, whereas we have ourselves found as many as 5000, and nearly as many in the queen. Drones, however, like all males which have to seek their females, have larger eyes, and the facets, Dr. Hicks (66) says, are larger and more numerous than those of either queen or worker. He also says that the hexagonal shape is assumed during the process of developement in consequence of their agglomeration, and points out as a proof that the external lenses, where not in contact with others, are round.

The reader will naturally ask the question: If there are so many eyes, how is a single true image of surrounding objects produced by the compound eye of the bee?

J. Müller (114) was the first who gave an intelligible explanation of the way insects see with their compound eyes. He regarded their eyes as a series of simple eyes, and that those rays of light which pass only through the crystalline cones, or are reflected from their sides, can reach the corresponding nerve fibril. The others are absorbed by the

pigment. No optical image is perceived, as each facet only gives the image of the object just in front, and each cone only receives light from a very small field of vision. The picture perceived by the insect was in fact a mosaic, and just as we see a pattern in mosaic composed of numerous inlaid pieces, so the image of an external object is supposed to be made up of the separate impressions caused by the rays of light proceeding from the illuminated points of the object seen, the number of points corresponding with the number of facets, the concurrence and combination of these separate impressions forming a picture, as it were, by the mind's eye. This theory was attacked by Gottsche (50), who pointed out that each separate cornea of a compound eye gives a separate and distinct image. Leeuwenhoek (91) had observed this, and said:—

'When I removed the tunica cornea a little from the focus of the microscope, and placed a lighted candle at a short distance, so that the light of it must pass through the tunica cornea, I then saw through it the flame of the candle inverted, and not a single one, but some hundreds of flames appeared to me, and these so distinctly (though wonderfully minute) that I could discern the motion of trembling in each of them.'

This experiment is easily tried, and is described in most books on the microscope. The eye of a dragon-fly is best for this purpose, if everything but the cornea be removed.

It is impossible for us to enter into the whole controversy, but we would here point out that when the

experiment is repeated and the crystalline cones are left *in situ*, the field of view appears perfectly black, with a bright spot of light at the end of each cone, and no trace of an image can be perceived, showing that the images of Leeuwenhoek are thrown by the cornea only. Lowne contends for Müller's theory, which is the one now generally accepted.

Besides the faceted eyes, bees have on the upper part of the head three simple eyes. Their disposition in the different sexes has been described in Chap. IV. (Fig. 7). They are called *stemmata*, or *ocelli*, but it is hardly correct to call them simple eyes, for their structure, as Leydig (95), who has studied them, points out, resembles very much that of the compound eyes. The cornea is very convex, and the crystalline cone, or lens, fits into a cup-shaped cavity, behind which are found structures similar to those described in the compound eyes. The eyes are similar, and the cornea and the crystalline lens have each become separately fused, while the rods which remain separate are brought close together. The ocelli are connected by nerves to the upper part of the brain and convolutions (pedunculated bodies of Dujardin, page 68). Each side of the brain sends nerves to the simple eye situated on the same side, the centre one receiving its nerves from the right and left sides. What, therefore, is the function of these different forms of eyes?

Our knowledge with regard to practical vision in bees is still very imperfect, although no one will deny that sight is highly developed. Lowne has cal-

culated by the angle formed by the lenses of the compound eyes that bees can at a distance of twenty feet distinguish objects from half to one inch in diameter. These eyes are therefore necessary for long vision.

With respect to the ocelli, Müller (114) considered that from their structure their power of vision was 'confined to the perception of very near objects.' The simple eyes bear a similar relation to the compound eyes as the palpi do to the antennæ. Both the antennæ and compound eyes, he says, are absent in the larvæ.

Lowne says: 'I strongly suspect that the func tion of the ocelli is the perception of the intensity and the direction of the light, rather than vision in the ordinary acceptation of the term.' The generally accepted view is, therefore, that the ocelli are useful in dark places and for near vision, while the compound eyes serve for seeing objects at long distances.

That bees possess the sense of colour there is little doubt, although we do not think that the experiments of Sir J. Lubbock (101) are at all conclusive in proving that bees have a preference for any particular colour. They simply show that bees can become accustomed to certain colours. G. Bonnier (9) has shown that, all things being equal, they do not visit flowers with bright colours more than they do others less brilliant.

We shall in another chapter (page 167) mention drones with white eyes. These, being destitute of pigment, render their possessors blind.

CHAPTER XVII.

DIGESTIVE APPARATUS.

Object of Digestion—Œsophagus—Honey Sac—Stomach Mouth—Its Use and Voluntary Action—Muscles—Prolongation—Structure of Chyle Stomach—Secreting Cells—Gastric Juice—Chyme—Small and Large Intestines—Malpighian Tubes—Gastric Teeth—Chyle—Rectal Glands.

THE object of digestion is to separate the nutrient part of food from the non-nutrient, and to convert the former into a liquid fit to mingle with the blood, and thus to nourish the body of the insect. This elaboration takes place in a cavity communicating with the exterior, into which the food is received, and from which the non-nutrient portions are expelled.

Many writers have described the digestive system, amongst whom are Swammerdam (158), Treviranus (163, 164), Brandt and Ratzeburg, Dufour (32), Réaumur (139), and others.

It is divided into four principal parts. The *œsophagus*, or gullet (frontispiece, *f*), which passes through the thorax, expands into an enlargement called the *honey sac*, or *honey stomach* (*g*) connected by a short neck to the *chyle stomach* (*i*), the small intestine, or *ileum* (*k*), and the large intestine, called *rectum*, or *colon*.

The food taken by the mouth enters the œsophagus, which continues through the thorax as a narrow tube, and expands, after it has reached the abdomen,

into the honey sac, this acting as a temporary reservoir for the collected nectar. From here the food passes on, to be digested by the action upon it of the gastric juices secreted by the cells in the chyle stomach. Or at the will of the bee the nectar may be regurgitated from the honey sac, and stored in the honey cells after conversion into honey. At the bottom of the honey sac is situated what Burmeister (17) has called the *stomach mouth* (*magenmund*), *h*. Although some thought its object was to prevent the too rapid passing of the food into the chyle stomach, others that it was a gizzard, Schönfeld (147, 149) was the first to discover the true use of this organ, and subsequently Schiemenz (144) gave a full description of it, accompanied by careful illustrations, from whose work our drawings (Figs. 47 and 48) are taken.

The stomach mouth is seen like a small pea, with two cross slits on the top, projecting a little on one side into the cavity of the honey stomach. It is of a brownish colour, and for its observation under the microscope Schönfeld recommends that this organ, from a freshly killed bee, should be placed in a solution of $\frac{3}{4}$ to $\frac{1}{2}$ per cent of salt in water, when the action of the lips may be seen for nearly half an hour. The muscular movements are very interesting, for the lips open and shut in quick succession, and, although involuntary under such circumstances, they give a faithful representation of the voluntary action of the stomach mouth in the living insect.

On examining the lips, it will be found that they are chitinous on the inside, with a row of

strong hairs pointing downwards along the edges (Fig. 47, *a*).

Looking down upon this organ, the disposition of the lips will be seen in the cross section through the middle (Fig. 48). Fig. 47 is a longitudinal section, and shows the narrow slit (*b*) which communicates

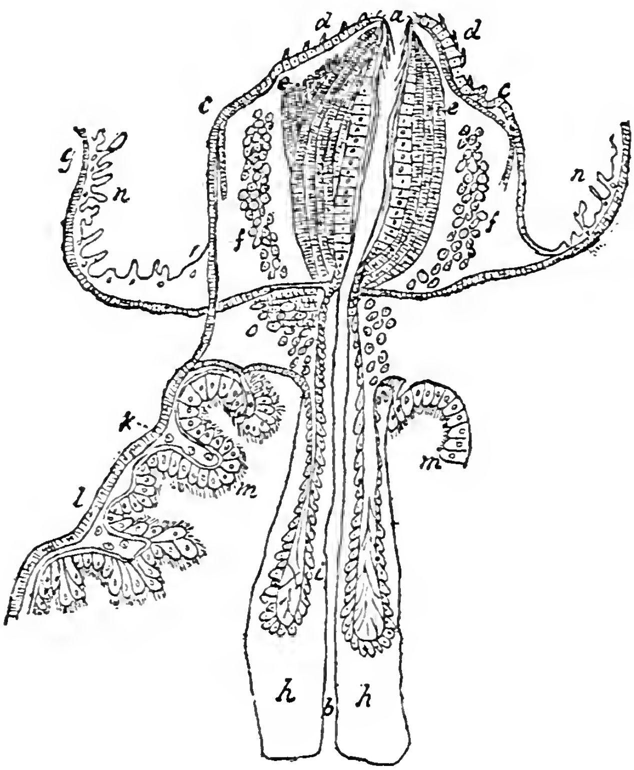


Fig 47.—Longitudinal Section through Stomach Mouth.

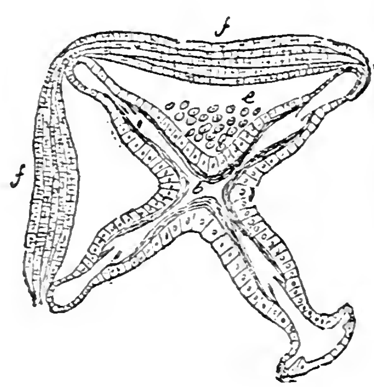


Fig. 48.—Cross Section of Stomach Mouth.

with the chyle stomach. In Fig. 48 this slit is cross-shaped. Each of the lips is triangular, with the row of hairs along its upper edges. The cross opening in Fig. 48 gradually assumes a circular shape as it extends into the neck, and the gaps at the ends are closed by valves. A strong membrane (Fig. 47, *c*) provided with hairs (*d*) covers the outside of the lips, and can be drawn up in folds, as seen in the illustration.

The stomach mouth is provided with two sets of muscles, the longitudinal ones (Figs. 47 and 48, *e*), and the others running round (Figs. 47 and 48, *f*).

By means of these muscles the lips can be opened and closed at the will of the insect. If the bee collects nectar and wishes to store it, the stomach mouth is closed by means of these muscles and the valves in the gaps, and by contraction of the muscular layer of the honey stomach (Fig. 47, *g*) it is forced through the œsophagus out of the mouth. If the bee wishes to eat both honey and pollen, the lips are opened by the strong longitudinal muscles (*f*) and form a funnel. The outer membrane (*c*) with its hairs (*d*) by its constant creasing, pushes the pollen grains up to the opening, where they find their way down with the honey. The down-pointing hairs (*a*) prevent the pollen from returning when the lips are closed (Schiemenz, 144).

Such is the construction of this stomach mouth, which Schönfeld says permits the bee to eat and drink when, where, and how she pleases, without having to trouble her mouth in any way. When a swarm leaves a hive, each bee takes with her as much honey as the sac will hold, and more than she requires for her own nutrition, as wax has to be produced and combs built. Or, if the weather be unfavourable for gathering after swarming, it is this stomach mouth which enables her to restrict voluntarily the consumption of the food she brought with her; and even in winter she can lay up a supply from the honey cells which will last her for days, to enable her to perform her duties and produce the necessary heat.

From the stomach mouth extends into the chyle

stomach a prolongation (Fig. 47, *h*) (*zapfen*) like a tube, containing nucleated cells, with a delicate membrane (*i*) which extends beyond these. This, Schiemenz says, when food is not passing through it, falls on one side and closes the opening, acting as a valve. The prolongation is in reality an infolding of the membrane of the chyle stomach, and its real use will be explained in the next chapter, when treating of brood food.

The chyle stomach bends upon itself from right to left, and is constricted at regular intervals by ring muscles (Fig. 47, *k*), longitudinal muscles (*l*) running along the whole length.

It is lined by an inner membrane (*intima*), with a layer of nucleated cells (*m m*) of various forms, which Schiemenz thinks have different functions, such as secretion of gastric juice and absorption, and outside this is an outer membrane (*propria*). The chyle stomach has a brownish appearance, from the pollen grains usually contained in it, and Schiemenz concluded that the object of the intima, which is tolerably strong, is to prevent these, or their skins, from coming directly into contact with the secreting cells, from amongst which it would be difficult to separate them.

By the action of the juice produced by these gastric glands upon the food, in the process of digestion in the chyle stomach, it is changed into *chyme*. This first stomachial digestion is called *chymification.*

The muscular walls acting upon the portion of unabsorbed chyme force it into the much narrower small intestine. At the commencement of this are a number of long tubes (frontispiece, *l*), which

have their openings into it, and are called the *malpighian* vessels, which have been specially studied by Schindler (145), who ascribes to them urinary functions. The lining membrane here is provided with gastric teeth, which further help to masticate any solid particles of pollen that may have escaped the soluble influence of the gastric juice.

The small intestine also curves upon itself (frontispiece, *k*), and by referring to section (Fig. 49) it will be seen that it is arranged in longitudinal cellular furrows, the intima being provided with downward-pointing hairs, which gradually disappear towards the end. There are no longitudinal muscles, but, on the other hand, the ring muscles (*a*) are strongly developed. A powerful sphincter muscle, close to the chyle stomach, enables this end of the intestine to be closed. In the intestine the digestion is completed and the food further absorbed, the colour of the contents being much darker than in the chyle stomach. The digested part of the food, in the form of *chyle*, has been absorbed, and the residue passes on to the next part of the alimentary system. At the end of the small intestine is found an enlargement; this is called the large intestine (frontispiece, *m*) or colon, and is of a much darker colour from the nature of the contents, the *excreta*. Near the commencement are seen oblong plates (frontispiece, *n*), the so-called rectal glands (*rectaldrüsen*) of Chun (24), which he care-

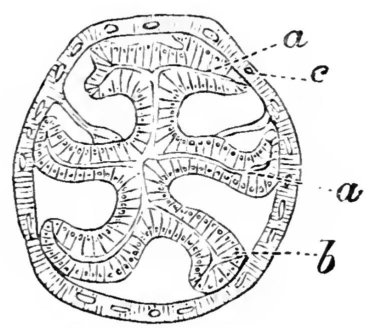


Fig. 49.—Section of Small Intestine.

fully describes in his memoir. They have also been described by Swammerdam, Burmeister, Dufour (*boutons charnus*), Newport (who calls them 'glandular protuberances'), Leuckart, Siebold, and others.

These glands project on the inner side, and are continuous with the intima. They are built up of layers of columnar epithelial cells, which on the surface present an irregular hexagonal appearance, and taper towards their other extremities. They are supplied with nerves, tracheæ, and muscles.

From the colon what remains of the undigested food is expelled by the anal opening (frontispiece, *o*). For this purpose strong muscles exist, by which the colon is compressed and the excreta ejected.

The quantity of the excreta voided, usually of a dark brown colour, is regulated by the nature of the food; bad honey, an improper substitute for honey (such as glucose) producing a larger amount, whilst good honey and good syrup produce less, a larger proportion of it being digested and absorbed. It is, therefore, important that bees should have good food, as in a healthy condition workers never void their fæces in the hive, but on the wing. In the winter it is retained until voided on their first flight.

The fæces of the drone are also ejected on the wing, and are of a greyish colour, from the nature of his food. Those of the queen, in consequence of her only feeding, as we shall see, on honey and chyle food, are liquid and of a pale yellow colour. We have seen them ejected by the queen in the hive, and, according to Vogel (166), they are sucked up by the workers.

CHAPTER XVIII.

GLAND STRUCTURE.

Four Systems of Glands—System I., or Sub-maxillary Gland—Hypo-pharyngeal Plate—Acini—Intracellular Structure—System II., or Sub-lingual Gland—Intercellular Structure—System III.—Reservoir—System IV.—Large in Queen—Functions of Glands—Royal Jelly and Brood Food—Schönfeld's Experiments—Chyle Food—How Chyle Stomach and Œsophagus are brought together—Chemical Analysis—Variation of Food—Microscopical Examination.

RESPECTING the glands in the bee we have a very complete literature, as they have occupied the attention of a large number of scientists, who have from time to time published their discoveries. The salivary glands in the honey bee have been divided into different systems, one pair being discovered by Ramdohr (136) in 1811, and two other pairs by Meckel (109) in 1846. There are two systems in the head and one in the thorax. These were further studied by Leydig (96) in 1859, Siebold (154) in 1872, Holz (*Bienenzeitung*) in 1877; and lastly we have all the systems, of which there are four, fully worked out and described by Schiemenz (144) in 1883.

We will describe each system separately, as given by Schiemenz, and then give his and other scientists' conclusions as to their functions and uses.

SYSTEM I.

This is found in the head, and is called by Meckel (136) the sub-maxillary gland. It has its outlet

by means of two circular openings on the hypopharyngeal plate (*schlundblättchen*) (Fig. 50, A B, *a*). These openings lead to sac-like hollows (*b*) noticed

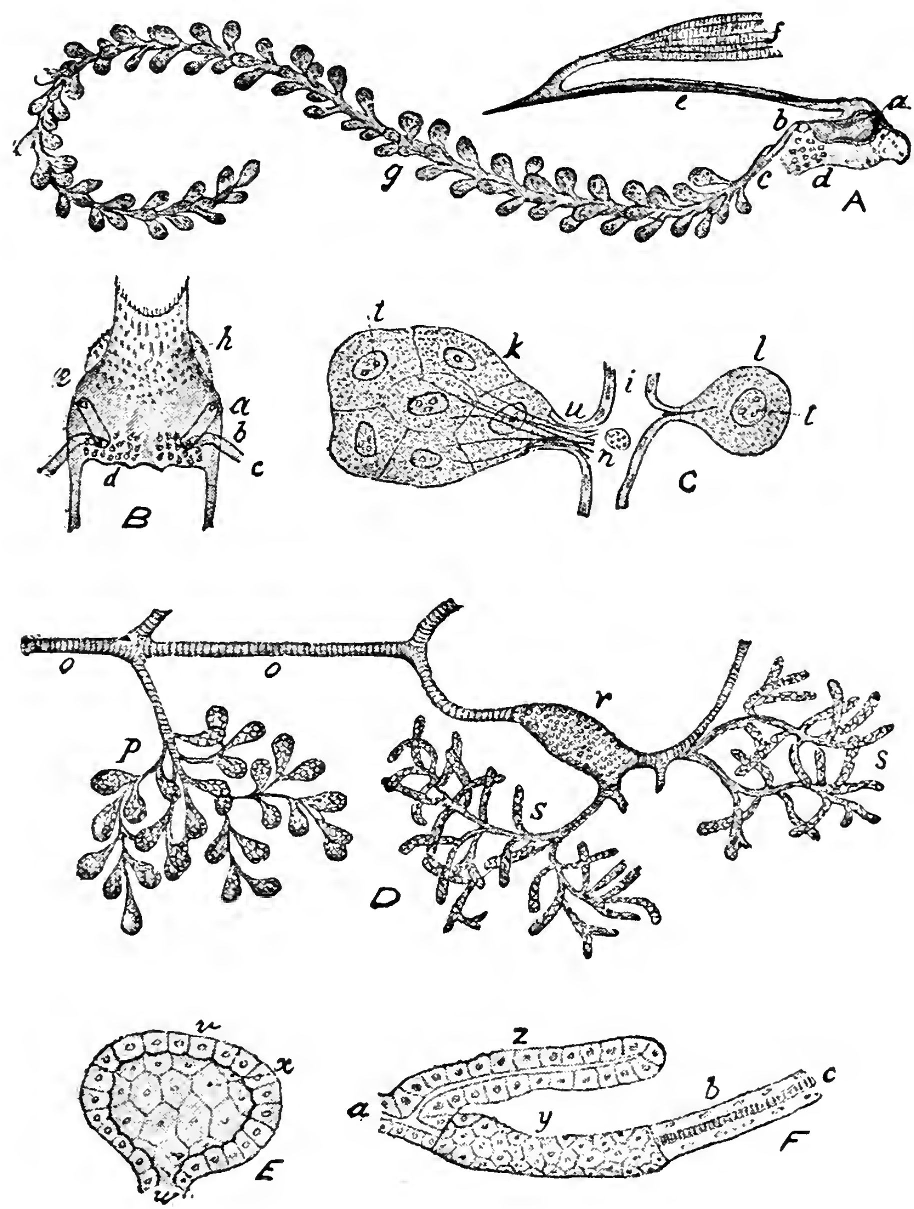


Fig. 50.—Glands.

and described by Wolff (170), and Holz, which lie in an oblique direction under the plate. On the under side they also have smaller round openings, leading directly into the ducts (*c*) of the glands

(*g*) which curve upwards and wind round the optic ganglion on each side of the head. Along the whole length, surrounding the duct to its blind end, are situated round or unequally shaped bag-like small granulations, composing the substance of these glands, called *acini*, and containing cells. The duct consists of a strong transparent tube, which is considerably thickened as it approaches the knee-shaped opening, and is from $\frac{1}{600}$ to $\frac{1}{800}$ inch in diameter. The cells in the acini, which are surrounded by the membrane (*propria*) through which the blood passes, produce the secretion.

Schiemenz (144) says these are *intracellular*, and that every part of the surface of each cell is absorbent. The secretion is conducted through ducts 0·002 mm. diameter, which enter each of the cell walls. After leaving the cells, they pass through a tube, where, by a sieve-like opening (C, *n*), they enter the main duct (C, *i*). The acini contain a variable number of cells (C, *k*), and Schiemenz found some with only one (C, *l*). They are very large in young bees (nurses), well filled, yellowish white; but the cell walls, although perceptible, are indistinct. In older workers the acini are very much shrunken, mulberry-shaped, yellow, and the cell walls cannot be recognised. The whole gland is surrounded by the outer membrane (propria), and the secretion from it is acid.

This gland is not developed either in the queen or drone. In the latter there is not the slightest trace of it, the hypo-pharyngeal plate having no perforations. On this plate in the queen the perforations are very

small, with a mere trace of a duct. Some queens seem to have this more developed than others, for Schiemenz found in three queens a groove where the opening should be on each side; in one of them, however, he found this groove only on one side.

System II.

This is also situated in the head, and was called by Meckel (109) sub-lingual gland (*glandula sub-lingualis*). This system has been described by even more investigators than System I., for besides Meckel, Leydig, and Siebold, we find it mentioned by Ramdohr (136), Treviranus (163), Dufour (32), and Fischer (44).

The duct which conveys the fluid secretion from this gland, as well as from that of System III., has its opening in the tongue (Fig. 23, *s*), then passing through the mentum, and continuing through the neck, it passes to the thorax, where it terminates in the two branches of System III. From this common duct (Fig. 50, D, *o*) the glands of System II. branch off, forming a cross with it, and running along the back of the head from the top downwards. The glands (*p*) are irregular-shaped, and are arranged like clusters of grapes. They are *intercellular*, and like a sac, lined with a single layer of cells so arranged that each cell presents a proportionately broad surface to the common cavity (Fig. 50, E), the material being obtained from the blood by the opposite ends next to the propria.

Each sac is composed of the propria (*v*), the

nucleated cell layer, and the intima (x). With a high magnifying power, the intima appears dotted, from pores through which, Schiemenz says, possibly the secretion passes into the sacs. On leaving the sac, the several ducts become creased and striped, and gradually develop into tracheal-like tubes.

The structure of this gland in the queen is similar, but larger, the cell layer being very much broader and more fully developed. In the drone this gland consists only of large masses of opaque yellow fat cells. These are the degenerated secreting cells.

System III.

Following the main duct (which has been described in System II.), we find it passing under the œsophagus into the front part of the thorax, and branching off on either side. Very soon the tubes expand into a reservoir (Fig. 50, D, *r*), which is shaped like a sac, having at its extremity two ducts leading in opposite directions. One of these travels towards the œsophagus, whilst the other takes a direction in front of the wing muscles.

The spiral structure of the intima of the main duct changes in the reservoir (D, *r*) to a membrane having star-shaped depressions. The ducts leading out of this have again a spiral structure, and the glands at the end are worm-shaped (Fig. 50, D, *s*) having constrictions along the intima of the central duct, on which is situated a layer of cells. This cell layer is continued over all the ducts, as well as the reservoir. Although this cell layer is very thin, over those in the

worm-like enlargements of the glands it becomes thicker and more fully developed, and nucleated cells appear, which are capable of producing a secretion, whereas those towards the reservoir lose this power. Over the continuous cell layer there is also found a propria. This system is also *intercellular*, and its structure is very similar in the queen and drone, the glands in these, however, being much smaller. The intima of the smaller reservoir in the drone, presents an irregular structure, owing to folds here and there, whilst in the queen it has only the spiral form of the other ducts, and the reservoir is even smaller than that of the drone, only appearing as a small swelling. The secretion of System III. is slightly alkaline, and almost neutral.

System IV.

This system has been described much later by Wolff (170) and Graber, as being an olfactory gland. Schiemenz and others, however, attribute to it a digestive function. It is in connexion with the jaws (Fig. 51), there being one attached to each jaw. If the jaw is carefully removed, this gland will be seen as an irregular-shaped oval sac (*f*), from which in a fresh state a strong-smelling, intensely acid liquid can be pressed out. The sac is connected with the jaw by a short curved tube (*h*), forming the intima. This gland is *intracellular* in type, and similar to System I., the canaliculi in connexion with the cells having each a separate opening in the jaw at *h*. Although in places the cells are very close

together, sometimes they have spaces between them like those in the intercellular type. The cell layer (*d*) which surrounds these, disappears near the bend. This gland, although large in the worker, is enormous in the queen, the cell layer is much more developed, and the openings of the more numerous canaliculi are set closer together, being surrounded by hairs. In the drone there is only a trace of this gland, the sac being very small, having a different structure, and the intima appearing in folds. The secreting cells are usually absent, or they are so shrunken that they are not capable of producing secretion.

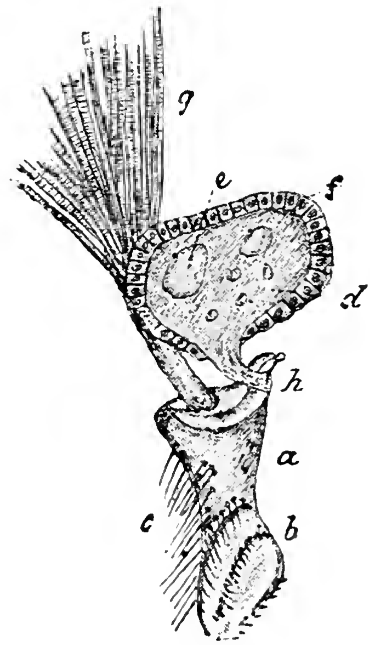


Fig. 51.—Gland. System IV.

Schiemenz says that System II., and in part System III., are derived from the spinning glands in the larva, whilst the others are new structures. The spinning glands will be described in the chapter on 'Metamorphosis' (page 162).

SUMMARY.

Having now described the glands and digestive system, we will endeavour to study their functions. The various functions ascribed to the glands are: The production of a secretion to assist digestion, to convert the cane sugar of nectar into the grape sugar of honey (Planta), for the elaboration of wax (Planta), and for the production of brood food, or for queen-feeding

(Schiemenz). This last view is also held by Vogel, Dzierzon (39), and Hilbert. Schiemenz, who follows Leuckart, comes to the conclusion that System I. produces the food both for the queen and larvæ, and points out that it is largest and most active in young worker bees, and that Systems II. and IV. have a digestive function. He sums up by saying: 'The food is not produced in the chyle stomach, but is a secretion from the glands. The principal one in its production is System I., although the other systems cannot be entirely excluded without further observation.' With respect to System IV., he points out that a queen who, for a body weight of 100 grammes, produces 11,000 grammes' weight of eggs in the year, and consequently requires great assimilating powers, has System IV. enormously developed. Leuckart (93) in 1855 discovered that the larvæ of workers were weaned, and after the third day had honey and undigested pollen (an error, as we shall presently see) added; the queen larva, however, received the same food during the whole of her larval existence, and he attributed to this the development of the ovaries. This, he said, was the difference between ordinary brood food and royal jelly. On the other hand, Dufour (32) taught that brood food was semi-digested and produced in the chyle stomach, while Schönfeld (147) has anatomically and physiologically demonstrated such to be the case. He points out that it is impossible for the bee to eject a secretion into the cells; that System IV. produces the saliva for various purposes, such as assimilation of

food, chewing pollen, kneading wax, acidifying brood food, and that it can only be poured out into the mouth when the bee masticates; that the other glands are for lubrication and converting the cane sugar of nectar into the grape sugar of honey. From the position of these, at the root of the tongue, it is impossible for the bee to place the secretion either in the worker cells or in an inverted position in the queen cells. Moreover, he found from practical experiments that if he mixed indigestible substances in the syrup on which bees were fed, that these substances reappeared in the larval food, even within six hours, showing that this food could be nothing but chyle, and not a secretion; for if it were a secretion, as these indigestible substances were not able to pass through the walls of the stomach, they could not have appeared in a glandular secretion, and they would not have been found in the larval food. Therefore Schönfeld comes to the conclusion that the brood food, as also that of the queen, called by Dzierzon (38), *milchsaft* (bee milk), is produced in the chyle stomach, and is pure chyle food. The digested food partly passes through the stomach into the abdomen, and forms blood, but when the bee requires it for brood food, the stomach is contracted, and by means of the transverse muscles (Fig. 47, *k*) the food is forced through the honey stomach into the œsophagus, and there receiving an addition of secretion from System I., it passes into the cells. Schiemenz ascribed to the prolongation (Fig. 47, *h*) in the chyle stomach the function of a valve, but Schönfeld has

demonstrated that it has quite another use. The prolongation he found to be an infolding of the membrane, and at the bottom of the honey stomach there was a mouth which opened and closed at the will of the insect. When the bee wishes to drive the chyle food from the chyle stomach into the cells, it forces the stomach mouth up to the œsophagus, as seen at Fig. 52, B, *c*, and the prolongation unfolds, extending the chyle stomach to the œsophagus, making a direct communication from *d* to *a*, through which the food is forced by the compression of the chyle stomach by its muscles. That this is possible Schönfeld has practically demonstrated, and has shown that the prolongation is just the right length for this purpose. The question has, however, been further solved, and Schönfeld's view that brood food is not a secretion has been confirmed by its chemical analysis by Dr. A. de Planta (132, 133), who found that the food not only differed with the various larvæ, but also that it differed at various stages of their development. He found, as Leuckart stated in 1855, that queen larvæ were fed with an abundance of the same food during the whole term of their existence, and that this food is chyle. The worker larvæ, on the contrary, receive similar chyle food the first three days, and on the fourth day it is changed, and then the larvæ are weaned, for the

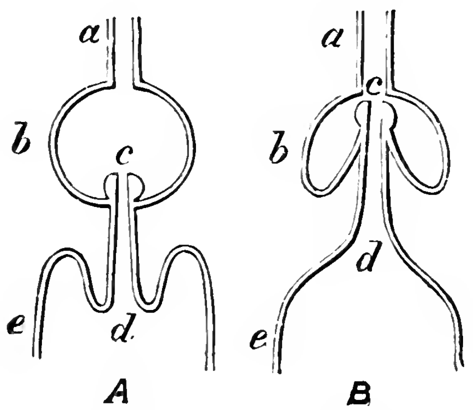


Fig. 52.—Diagram of Stomach Mouth and Prolongation.

first pap has a large quantity of honey added, but no undigested pollen, as Leuckart had stated. The drone larvæ are also weaned, but in a different way, for in addition to honey, a large quantity of undigested pollen is added to the food after the fourth day.

The following table gives the percentage of solid constituents of the food at various periods:—

	Albumen.	Fatty Substances.	Sugar.
QUEEN.	**45·14**	**13·55**	**20·39**
DRONES.			
Under Four Days	55·91	11·90	9·57
Over Four Days .	31·67	4·74	38·49
Average	**43·79**	**8·32**	**24·03**
WORKERS.			
Under Four Days.	53·38	8·38	18·09
Over Four Days .	27·87	3·69	44·93
Average	**40·62**	**6·03**	**31·51**

Microscopic examination showed that in the queen and worker larvæ there was no undigested pollen, whereas in the drone larvæ after the fourth day large numbers of pollen grains were found. In one milligramme no less than 15,000 pollen grains were counted, and these were from a number of different plants. Although saliva from the glands (especially System I.) is probably added to the food, this cannot, from its great variability, be entirely a secretion, as stated by Schiemenz. This work of Dr.

Planta's, we think, conclusively proves that the food is not a secretion, and that the nurses have the power of altering its constituents as they may require for the different bees.

It is easy to understand how former observers have gone wrong. If all the food taken from worker and drone cells over four days is mixed up, of course pollen will be found, and this misled Leuckart and those who have followed him. Dr. Planta is the first who has made a separate analysis of the food on different days, and of the different bees, and he is also the first who has by his experiments corroborated Schönfeld's opinion.

Royal jelly is, therefore, chyle food, and this is also most likely the food given to the queen bee. Schönfeld (148) has also recently shown that drones are likewise dependent upon this food, given to them by workers, and that if it is withheld they die after three days in the presence of abundance of honey. This, he thinks, accounts for the quiet way in which the drones perish at the end of the season.

It will now be easily understood that if weaning of the worker larvæ does not take place at the proper time, and that the first nourishing food is continued too long, it may be the cause of developing the ovaries, and so produce fertile workers, just as the more nourishing food continued during the whole of the larval existence in the case of a queen develops her ovaries, or even in the absence of a queen the feeding of workers on this rich food may tend to have the same effect. This, then, is the solution of royal jelly and brood food.

We may here remark that when the tongue is drawn back, the opening of Systems II. and III. is closed, and that of System I. open, and that this is just the right position for adding this secretion as the chyle is driven out. But only when the tongue is drawn out, as in sucking, is the outlet of Systems II. and III. opened, and it is then just in the right position to mix with the nectar as it is sucked into the honey stomach.

Berlepsch (3), who describes these glands, and Holz (*Bienenzeitung*), also hold the view that secretion from System I. is added to the chyle food.

CHAPTER XIX.

DRONE ORGANS.

Description of Organs—Vasa Differentia—Vesiculæ Seminalis—Spermatic Tubes—Structure of Spermatozoon—Mucus Glands—Bean—Armor Copulatrix—Spermatophore—Pneumophyses—Expulsion of Spermatophore—Inversion of Organs—Masque—Impregnation of Queen only on the Wing—Death of Drone—Why so many Drones are produced—Selection of the Fittest—Expulsion of Drones.

WE have already mentioned, on page 8, that the drone is only needed during the summer season, and has only one function to perform, that of impregnating the queen.

The sexual organs have been studied and described by more naturalists than any others, amongst some of whom may be mentioned Swammerdam (158), Réaumur, (139), Huber (68), Vogel (166), and Girard (48). We shall in the main follow Girard's and Vogel's description.

By referring to Fig. 53, it will be seen that these organs consist of two testes (*a a*), two tubes (*vasa differentia*, or *samenlister* of the Germans), two seminal vesicles (*vesiculæ seminalis*), two large *mucus* glands (*b b*), the *ductus ejaculatorius* (*c*), and an organ of generation. The testes (*a a*), are white, oblong, slightly flattened glands, much smaller in the adult than are the ovaries of the queen, and they lie in the abdomen on the dorsal side, on each side of the digestive organs. They are made up of spermatic tubes, in number about

300, which open into the vasa differentia, the ducts just below them. It is in the chrysalis of the drone that the testes have the greatest development, nearly equalling at this period the ovaries of the queen. These canals are then filled with ripe spermatic tubes, and

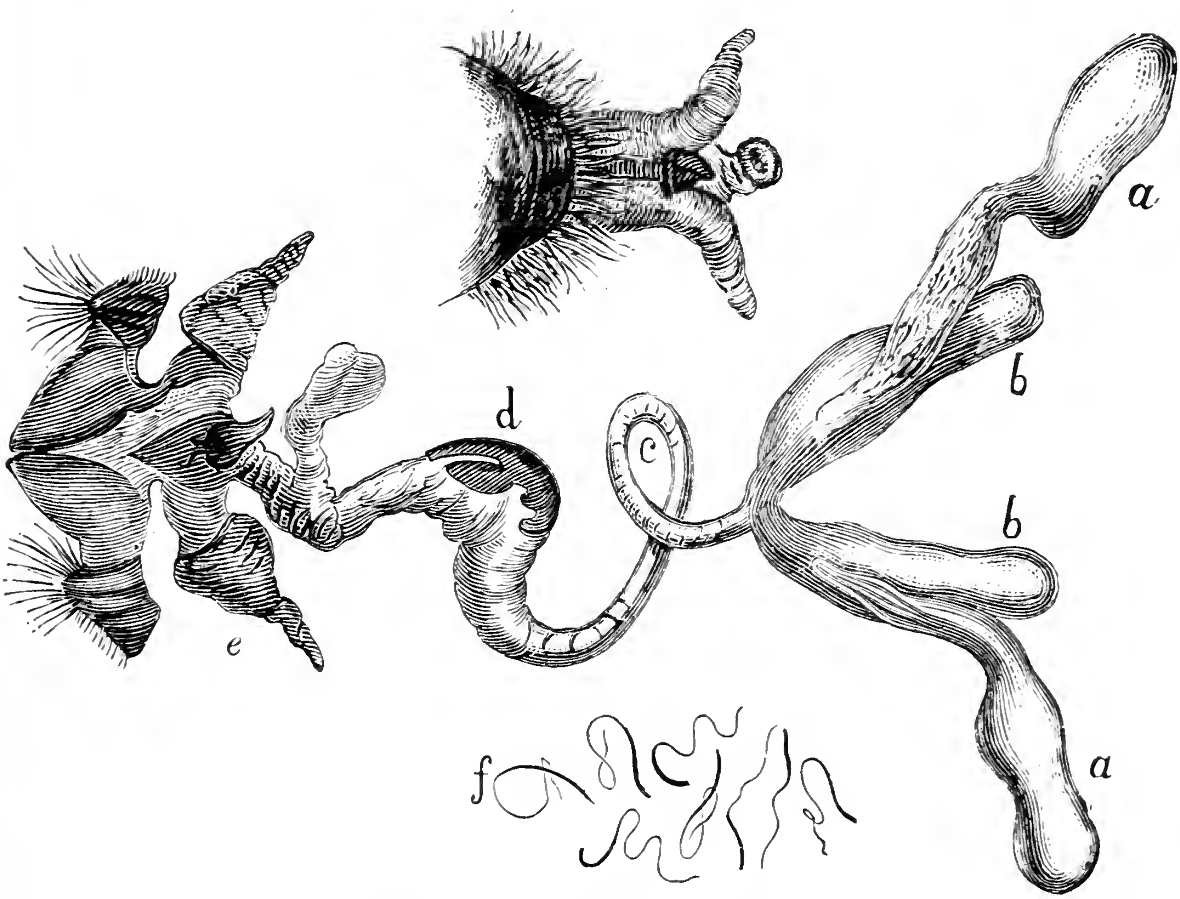


Fig. 53.—Drone Organs.

with filamentous spermatozoa (*f*) endowed with a lively serpentine movement, which Girard (48) has likened to a field of corn oscillating under a gentle breeze. Girard says in the adult most of the spermatozoa have passed into the seminal vesicles, and the testes shrink and flatten, their membranes being traversed by numerous tracheal tubes.

The spermatozoon is structurally a cell, and differs

from the ovum in a marked manner. Whereas in the ovum there is a cell substance and a nucleus, in the spermatozoon the cell substance is reduced to a minimum. Geddes (45) says it is of a definite type, and has a minute 'head,' consisting almost entirely of nucleus and a long contractile tail, which, working behind like a screw, propels the essential 'head' through the water, or ducts. In shape it somewhat resembles the 'great reed-mace,' commonly called 'bulrush.'

The vasa differentia are narrow tubes, which, after several spiral turns, join the seminal vesicles, connected at their narrower extremities to the *mucus glands* (*b b*). These secrete a gelatinous fluid, which hardens and gives the spermatozoa cohesive power. The seminal vesicles at the entrance to the mucus glands unite with the *ductus ejaculatorius* (*c*), which is provided with well-developed muscular walls, acting in forcing forward the spermatozoa. The rounded fleshy white body is called the *bean*, or *lentil* (*d*), united by two crescent-shaped scales, and two triangular ones, which Girard says are rudiments of the genital armature (*armor copulatrix*) of the hymenoptera. The bean and the remaining parts are surrounded by a membranous covering. Below the bean on the covering are found five or six brown ridges; these are curved tubercles covered with stiff hairs, which prevent the withdrawal of the organ from the vagina of the queen, and aid in its rupture. The spermatozoa are forced into the bean, which they fill, and their mass is now called the *spermatophore*.

Below the ridges are situated two membranous sacs (*e*) in the shape of horns, more or less filled with air, their openings communicating with the exterior. These are the *pneumophyses*, or air vessels (*vessies aérifères* of Dufour). When sunk they are bent and depressed; but when filled out and well developed they become hard and tough, taking the form of straight or curved divergent horns. If they are dried in this state the membrane preserves its form and acquires a papery consistence.

The spermatophore is pear-shaped, and gives the upper part of the organ a bulbous appearance. The expulsion of this spermatophore has a curious effect on the different parts of the organ, which are thereby turned inside out. The organ lies loosely in the cavity of the abdomen, and only adheres to the body at the edges of the sexual orifice. Girard (48) says it behaves somewhat like the finger of a glove turned outside in, which, upon blowing into the glove, filling it with air, and then compressing it, will be gradually forced out.

If the termination of the abdomen of the drone be examined, it will be found very blunt and slightly turned under, so that the orifice is below. By well-regulated pressure on the internal organs, we first force out of this opening and bring into view a greyish rounded body (*masque* of Réaumur), covered with thickly set spines. The pneumophyses (*e e*) then show themselves, unroll, fill out by the introduction of air, and the 'masque' is then found in front of their bases (to the left in illustration), the organ being turned

inside out. The same thing occurs during coition, and it is then that the curved spines prevent the withdrawal of the organ. Girard says the force which determines this change is derived from the pressure the drone brings to bear upon the sexual apparatus by a violent contraction of the abdominal muscles.

The different parts of the reversed organ appear outside one after the other, as far as the bulb, and it is then that the spermatophore is discharged. The more the abdomen is filled and distended the more easily is the organ extruded. When the drone flies out the tracheæ and sacs are well filled with air, and this considerably increases the pressure exercised on the sides of the abdomen. This is why coition can only take place on the wing, and the upward turning of the organ does not permit it to act on insects on the ground. This also explains why Huber never saw the *accouplement* between the drone and a virgin queen shut together in a box. In repose, the tracheæ not being inflated, the pressure would be insufficient for that complete reversing of the organ which is necessary for the projection of the spermatophore, and for its introduction into the vagina and spermatheca of the queen.

After the expulsion of the spermatophore, the drone dies, and the queen returns to the hive with a fragment torn from the organ, resembling a filament, or white thread, hanging from the vagina—a sign of impregnation. What we have just described is not only true of drones brought up in the normal cells of their sex, the issue of a fertilised mother, but

for all indifferently. Those born of mothers not impregnated, or drone breeders, are as perfectly developed and as fully virile as the others. This may be said of drones raised accidentally in queen cells, dwarf drones raised occasionally in worker cells, and drones from fertile workers. Leuckart has well established the fact, for he found drones produced by an Italian fertile worker which gave, mated with black queens, workers of the mixed races (*mellifica* and *ligustica*). In these drones raised from fertile workers identically the same spermatozoa were found as in the others.

From what has been said, it will be seen that as only one done is required to impregnate a queen, the question naturally suggests itself, Why are there so many reared? It is well known that drones are reared in the spring, at the beginning of the swarming season; and at the close of summer, when stores are becoming scarce and all further chance of their being required for the purpose of their existence, viz., fertilising a queen, is at an end, they are ruthlessly turned out of the hives, and, as Schönfeld (148) has shown, they are allowed to starve by the workers withholding the chyle food from them. Some races rid themselves of their drones much sooner than others, and the late Rev. G Raynor stated in a discussion on Mr. Haviland's paper, 1882 (62):—

'He noticed that Cyprians destroyed their drones more expeditiously than any other race of bees that he had knowledge of. When it was determined that the drones should be expelled, they set to work with so good a will

that in from four to six hours the entire drone population was driven from the hive, and so strict a guard over the hive was kept that not a single one could regain an entrance; while with black bees the operation often extended over several days, causing great commotion in the hives.'

It has been supposed that drones keep up the temperature of the hive. We have no doubt they do to a certain extent, and enable worker bees to go out; but considering that they are produced principally in summer, when they are hardly required for heat production, and that they consume a large quantity of food, it is at great expense to the colony that they would do this, and the same purpose could be accomplished by rearing a larger number of workers. This is done by the bee-keeper preventing the production of drone brood. The queen is the life of the colony, and when bees swarm she leaves with them. The young queen, before she can lay eggs that will produce workers, requires to be impregnated by a drone, and this can only be accomplished, as we have seen, on the wing. It is evident if there were only a few drones, the chances of her meeting with one when out would be less than if there were a large number. She runs many risks when out on her wedding flight, which would be greatly increased if she left the hive frequently and returned without mating. In the discussion above alluded to (see *B. B. J.*, 1882, page 168), we said:—

'As far as his (Mr. Cowan's) observations went, the fertilisation took place in the open air, and he thought it

was good for the queens that it should take place there, because when the young queen flew out for fertilisation, after taking observations of the surrounding neighbourhood, she flew away at an enormous speed, and therefore the strongest and swiftest drone had the queen for a mate. In this way they had again the selection of the fittest. Were fertilisation to take place only in the hive, instead of the breed improving, it would be deteriorated.'

Besides this, we have seen that to expel the spermatophore to fecundate the queen requires great force; it is therefore evident that only the strongest drones are capable of doing this. Weak drones, whether their weakness is caused by improper or insufficient nourishment in their larval state, have not their organs properly developed, consequently the spermatophore may not be a compact mass of spermatozoa, as it should be. The strongest drones are the swiftest, and the best for the purpose they are intended for. This, we think, explains the reason why these apparently useless creatures are tolerated, and are only expelled when their services are no longer needed.

CHAPTER XX.

QUEEN ORGANS.

Ovaries—Follicles—Development of Ovum—Number of Eggs and Egg Germs—Oviduct—Bursa Copulatrix—Spermatheca and its Use—Valvular Controlling Muscles—Appendicular Glands—Large Number of Spermatozoa—Decrease in Fertility of Queens—Microscopic Examination—Valvular Joint—Nuptial Flight—How soon Impregnation takes place—The effect if delayed—No notice taken of Unimpregnated Queen by Workers—Drone-breeding Queens.

THE ovaries of the queen are, from their size, easy to find and recognise. Their position, as shown by Leuckart (93), is seen at E in Fig. 54, which is a longitudinal section through the abdomen of a

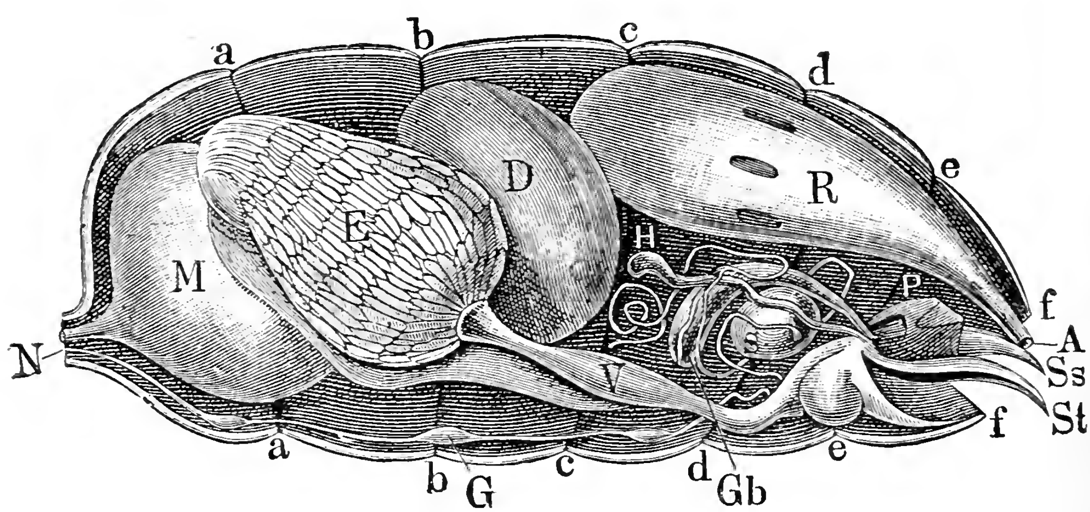


Fig. 54.—Section of Abdomen of Queen.

queen bee, the queen organs being the homologues of those of the drone. In the same position as we found the testes in the drone we shall find in the queen two large pear-shaped organs, called ovaries (Fig. 55, A, *a a*). They are found below the second and third abdominal

rings on either side of the honey sac and chyle stomach. Like the testes, they are tubular glands, and on each side there are from 180 to 200 tubes,

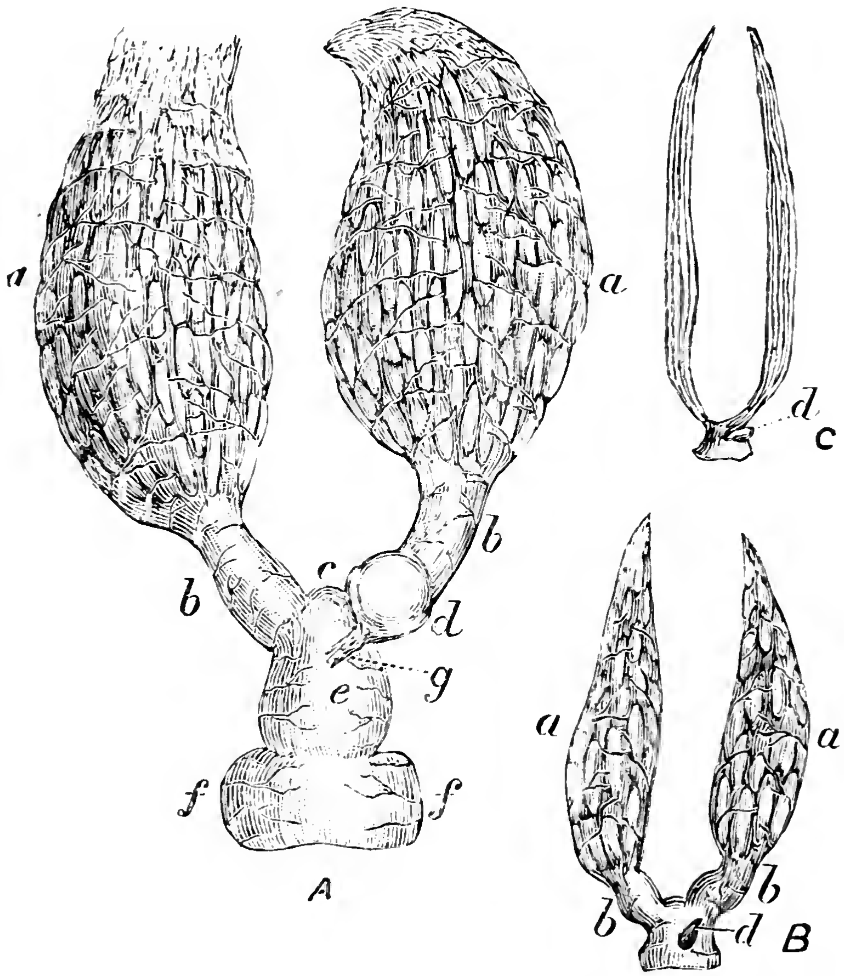


Fig. 55.—Ovaries of Queen, Worker, and Fertile Worker.

or *follicles*, interlaced with fine tracheal ducts, which connect the ovarian tubes into bundles.

The development of the eggs takes place in the ovarian tubes. The ovum presents all the features of a cell, with the cell substance, consisting of protoplasm and the nucleus, or 'germinal vesicle.' The first germ cell appears at the upper blind end (Fig. 56) of the tube, and as it becomes developed (by a process

too intricate for us to enter into here), passes on, gradually enlarging and acquiring a darker colour; then the yolk (*vitellus*) appears, and when it reaches the bottom of the tube it is surrounded by an outer skin, or egg-shell (*chorion*) (Fig. 57, D, E). Fig. 56 shows one of the tubes, with the gradual development of the egg. We see that as the egg grows swellings are produced, which gradually increase in size as it becomes larger and more fully developed. The cells between each egg also grow and produce similar swellings, so that in a laying queen they appear somewhat like a pearl necklace. Leuckart says egg germs are later in making their appearance in the queen than are the spermatozoa in the drone. He did not find them in the insect just emerging from the chrysalis, whose ovarian tubes are filled with pellucid globules, similar to those that precede the appearance of the seminal filament in the drone testes.

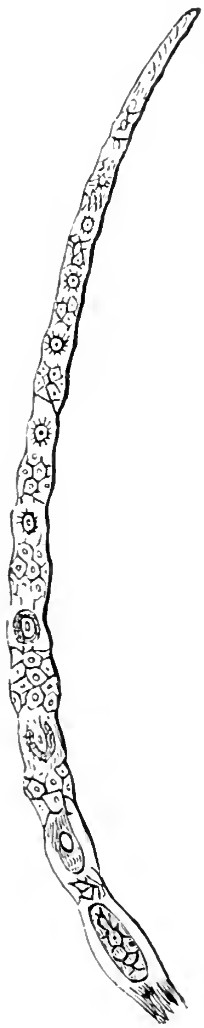


Fig. 56. Ovarian Follicle.

During the breeding season each follicle contains more than a dozen white eggs (Leuckart*) standing end to end, like the beads of a necklace, in various stages of development, of which one or more at the lower end of the tube are ripe, so that the number of eggs and egg germs must reach from four to five thousand.

* *Bienenzeitung*, 1857.

In winter the number of egg germs will be reduced to one-half, while scarcely any perfect eggs will be found, so that the ovaries decrease in size. In a virgin queen, before the eggs begin to develop, the tubes only contain cells, therefore the swellings are absent. The tubes have their separate openings, which unite at the commencement of the *oviducts* (Fig. 55, *b b*), forming beneath them a trumpet-shaped cavity, having thicker outer walls than the tubes of the ovaries. The oviducts are provided with longitudinal and transverse muscular fibres, which give them great elasticity. The two tubes of the oviducts unite at *c*, continue as a single oviduct, and expand, forming the vagina (*e*), furnished with strong muscular walls. The vagina has on either side two pocket-like swellings (*bursa copulatrix*, *f f*), which receive the two horned pneumophyses of the male organ. The opening of the vagina appears as a long slit at the edge of the last ventral plate. Between this and the last abdominal plate are situated the sting and the poison glands, which are placed between the vagina and the chyle stomach. Connected by a tube, having its opening near the commencement of the common oviduct, is a small globular sac, called the *spermatheca* (*receptaculum seminis*, *d*). Its use was first discovered by Audouin, and described by Huber (68), but it was more particularly studied and described by Siebold (153), and its true significance pointed out. It receives and holds the millions of spermatozoa derived from the drone, and is large enough to be seen with the naked eye, being about the size of a grain of

millet. On the outside it is densely coated with tracheæ, which interlace so thickly that they give it a white silvery appearance. Leuckart says these tracheæ only lie on the surface, and can easily be removed, or pealed off, and then expose the membrane of the spermatheca. The tube connecting the spermatheca (*d*) with the vagina (*e*) is provided with muscles, by means of which it can be opened or closed for allowing or preventing the passage of the spermatozoa. These powerful and complicated muscles, discovered by Leuckart (93) in 1858, and which were also seen by Siebold (153), are situated very near the connexion of the spermatheca with the tube ; they gird and bind it as with a thick ring forming a swelling, so that when they come into operation the duct may be opened or closed, and thus allow the spermatozoa to pass, or to keep them back in the spermatheca (Leuckart). On the outside of the spermatheca we find two glands, which pass down the opposite sides, meeting together and forming a junction near the spermathecal duct, which the tubes of the glands enter. These glands are called *appendicular*, and their cells secrete a liquid which mixes with the spermatozoa and preserves their vitality unchanged for a very long period. It is close to the opening of these tubes into the spermathecal duct that the valvular muscles are situated.

Siebold and Leuckart both found that if the queen is unimpregnated the spermatheca contains no traces of spermatozoa, and only a clear fluid, which is supplied by the appendicular glands and

epithelial cells of the spermatheca. In an impregnated queen, on the contrary, the contents of the spermatheca are opaque and milky white, being filled with an enormous number of mobile threads (spermatozoa), identical with those of the drone, described on page 127.

As a fertile queen advances in age the number of spermatozoa decrease, and the spermatheca will be seen only partly filled. Leuckart says the spermatheca may contain 25,000,000 spermatozoa, and as its contents have to last during the whole lifetime of the queen, she is able to economise them and give them up just as needed for fertilising the eggs. A queen may lay for four or five years, but her fertility decreases in proportion to the number of eggs she lays. We have found queens at the end of three years having so few spermatozoa that they rarely, if at all, fertilised the eggs, and consequently became drone breeders. It is many years ago since we first pointed out that with our system of stimulation and forcing queens to lay a large number of eggs, after the second year the fertility of the queen decreases, and she becomes no longer profitable to the bee-keeper; hence we have always advocated the rearing of young queens to supersede old ones. This experience of ours would also show that the number of spermatozoa as given by Leuckart is excessive, or that there is great waste in their use. We must now explain how the spermatozoa are forced into the spermatheca. When the inversion of the male organ takes place the horns are forced into the bursa copulatrix (Fig. 55, *ff*), which

they fill, the remaining parts of the inverted organ occupying the space above, the spermatophore being forced against the top of the common oviduct (*c*). The pressure exerted by the muscular coat of the vagina prevents the contents coming outside, and the spermatozoa are driven into the oviducts (*b b*). Leuckart (93) was able to prove this by a microscopic examination of three queens just after impregnation. In all the three queens the oviducts were swollen out considerably, and contained a large number of spermatozoa, while the spermatheca contained either none or very few. The contraction of the muscles of the oviducts drives the spermatozoa into the spermatheca. Leuckart also found in the walls of the vagina, opposite to the outlet of the spermathecal duct, a valvular joint, which closes the lower end of the common oviduct, the muscular walls of which exert a pressure which assists in forcing the semen into the spermatheca.

In order that a queen may lay eggs that will produce females she must leave the hive for impregnation, and this takes place, as we have seen, in the air. Janscha (73) was the first to observe that the queen, when she left the hive for the first time, after crawling about on the alighting board, flew a few feet from the hive with her head towards it, and then proceeded to fly in horizontal circles, gradually extending them. After a few minutes she returned to the hive. Often her second flight takes place a few minutes after the first, and it is not until she has made herself thoroughly acquainted with the locality that she takes her wedding flight.

Moufet (111) in 1634, first advanced the idea that fecundation took place in the air, which has since been confirmed by Huber and others. The queen usually leaves the hive for impregnation from the third to the fifth day after leaving her cell. Berlepsch (3) says he has never known a queen to be impregnated earlier than the third day, although impregnation may be delayed considerably beyond the fifth day, more especially if the weather be cold. If delayed beyond the twenty-first day, she lays, as Huber (68) observed, only eggs that produce drones, although Berlepsch and Dzierzon found that occasionally exceptions occur, and that a queen in such cases becomes properly impregnated at thirty days, and in one case forty-seven days. Generally the flight takes place during the finest hours of the day, between twelve and four o'clock in the afternoon. Seldom later, and yet more seldom earlier. Before she flies for impregnation the bees take no notice of the queen, and do not even feed her, nor does she take any notice of the workers. The drones are also quiet. The time she stays out varies from three to ten minutes, but it is sometimes reduced to only one minute, and may be extended to forty-five minutes. When she returns to the hive after having mated successfully, she never leaves it again, except with a swarm, and is able henceforth to lay eggs which will produce either females or males, a fact which puzzled Huber and others. She begins to lay eggs usually about forty-eight hours after impregnation.

If from some cause she does not find a mate within the proper time, she is still able to lay eggs,

but from these only drones will be evolved, the reasons for which will be explained in the next chapter.

If a queen is noticed on her return after mating with a drone, it will be seen that she carries the unmistakable signs of impregnation, by portions of the drone organ remaining attached. This was first observed and recognised by Janscha (73), and also later by Huber (68), in 1791, as portions of the male organ. Their observations were confirmed by Siebold (*Bienenzeitung*, 1854, p. 227), to whom Berlepsch sent a specimen, and who made a careful microscopical examination.

CHAPTER XXI.

PARTHENOGENESIS.

Dzierzon's Discovery—Summary of his Theory—Theory proved by introduction of Italian Queens—Drones of Cross-mated Mothers Pure—Egg—Structure—Micropyle—Spermatozoa found in Eggs—Those producing Drones contain none—One sufficient for Fertilisation of Egg—Impurity of Drones—Prolonged Vitality of Spermatozoa—Result of Freezing Queens—Paralysis producing Drone-breeders—Arrenotokia—Homology between Drone and Queen Organs—Good Drones important—Ovaries of Worker and Fertile Worker—How Bees replace a Lost Queen.

REPRODUCTION without fecundation is called *Parthenogenesis*, and although known to exist in other insects in the first half of the eighteenth century, having been observed by J. P. Albrecht (153) of Hildesheim, in 1701, was not known in bees until it was discovered by Dr. Dzierzon, who first commenced to think about it in 1835; but it was not until 1842 to 1844 that he made known his ideas about this new theory in a small local paper, called *Frauendorfer Blätter*. In 1845 he published his discovery in the *Bienenzeitung*, and this drew the attention of scientists to the subject. Dzierzon was able subsequently to establish his theory as a fact.

Siebold (153), who knew the importance of this discovery, speaks of Dzierzon 'as one of the most experienced and credible bee-keepers amongst living apiarians,' and Prof. Cook (27) says: 'As a student of

practical and scientific apiculture (he) must rank with the great Huber.' Siebold also says of the theory: 'By this all the mysteries which we have hitherto vainly endeavoured to unriddle are completely solved.'

In 1849, Dzierzon (37) summed up his views upon the reproduction of bees in the following words:

'Therefore, and this must be well borne in mind, in the copulation of the queen, the ovary is not impregnated, but this vesicle, or seminal receptacle, is penetrated or filled by the male semen. By this, much, nay all, of what was enigmatical is solved, especially how a queen can lay fertile eggs in the early spring, when there are no males in the hive. The supply of semen received during copulation is sufficient for her whole life. The copulation takes place once for all. The queen then never flies out again, except when the whole colony removes. When she has begun to lay, we may, without scruple, cut off her wings; she will still remain fertile until her death. But in her youth, every queen must have flown out at least once, because the fertilisation only takes place in the air; therefore no queen, which has been lame in the wings from birth, can ever be perfectly fertile: I say, perfectly fertile, or capable of producing both sexes. For, to lay drone eggs, according to my experience, requires no fecundation at all. This is exactly the new and peculiar point in my theory, which I at first only ventured to put forward as a hypothesis, but which has since been completely confirmed.'

Also, in 1855 (*Bienenzeitung*, p. 201), he says:

'All eggs which come to maturity in the two ovaries of a queen bee are only of one and the same kind, which, when they are laid without coming in contact with the

male semen, become developed into male bees, but, on the contrary, when they are fertilised by male semen, produce female bees.'

This theory was subjected to a most searching investigation by Siebold, Leuckart, and Berlepsch, and was confirmed by them. The introduction of the Italian bee by Dzierzon in 1853 set at rest any doubts there might have been, for it was proved that if a pure Italian queen mated with a black drone, her drones, with few exceptions, to be alluded to later, will be pure Italians, while her female progeny will partake of the qualities and characteristics of the two races.

If, also, a black queen mate with an Italian drone, the females, both workers and queens, will be crossed, while the drones will be pure blacks. It is therefore evident that the drone has no father, and proceeds only from the mother. This fact still remained to be proved anatomically, and Siebold and Leuckart were able to do so. If an egg be examined, its surface, or chorion, is seen to be covered with a delicate hexagonal lattice-work (Fig. 57, D, E), as with a network, radiating, and in the centre will be found a minute aperture, the micropyle (Fig. 57, D), through which the spermatozoon enters, when the egg passes the spermathecal duct.

Siebold, who examined the eggs of workers by crushing them immediately after they were laid by the queen, found the spermatozoa within. He says: 'In thirty I could prove the existence of the seminal filaments in which movements could be detected in

these eggs.' In some of them he says he found as many as three, and in twenty-four only one. He subsequently carefully examined eggs taken from drone cells, treating them in the same manner, and says that he 'did not find one seminal filament in any single egg, either externally or internally.'

It is possible that Siebold may have found more than one spermatozoon in some of the eggs, and until recently it was believed that more than one might enter the ovum, but Geddes and Thomson (45) point out that—

'Researches such as those of Hatwig and Fol have shown that when one sperm has found admittance, the way is usually barred against all others. The micropyle may be blocked, or the surrounding membrane may be altered, or in other ways the ovum may exhibit what Whitman calls 'self-regulating receptivity,' so as to be no longer penetrable. We are safe in concluding that the ovum is usually receptive only to one sperm; that in most cases the entrance of more than one sperm is impossible.'

Why and how the spermatozoon finds its way to the micropyle is involved in mystery; but Geddes and Thomson (45) point out that the theory of Rolph is being accepted as the most probable one, namely, that 'the less nutritive, and therefore smaller, hungrier, and more mobile organism' (cells, he is speaking of) 'we call the male; the more nutritive, and usually more quiescent organism is the female;' and he goes on to suggest why 'the small, starving male cell seeks out the large, well-nourished female cell for the purpose of

conjugation, to which the latter, the larger and better nourished it is, has on its own motive less inclination.'

Although we have seen that parthenogenesis in the honey bee is the rule, it has been observed that sometimes the drones do not appear to be pure, and bear unmistakably hybrid characters. J. Lowe (98) and J. Perez (123), independently of each other, have carried out experiments with a view to proving whether drones did sometimes exhibit traces of a mixed parentage. Perez found that although by far the largest number of the drones partook of the character of the mother, as many as twenty per cent showed a mixed character. Cameron (19) has lately also drawn attention to this fact, which has been frequently noticed by bee-keepers and others, who have thereupon declared the Dzierzon theory untrue. That parthenogenesis is the rule, there is no doubt, but it is equally true that such variations have been observed to exist. Various reasons have been assigned for this deviation from the rule laid down by Dzierzon, and confirmed by Siebold and other observers. One was that the drones were probably bred from workers of different sorts, another that they were cases of atavism; but the most probable view is that held by those who believe that these drones are produced parthenogenetically, but that the male of a different race may have so influenced the ovary as to affect the future progeny. Lately, Mr. Grimshaw (59), in a paper on 'Heredity in Bees,' read before the B. B. K. Association, advanced the idea that heredity is transmitted through the food

supplied by the nurse bees to the larvæ, and that therefore the progeny of the queen by this means partake of the characteristics of the workers, as well as those of the queen. If this applies to workers, why should it not do so to drones? It would not be at all impossible in such a case that drones could partake of the character of the workers, and although they may be parthenogenetically produced, the food administered through the workers may have influenced their character, and imparted to some of them the outward characteristics of the workers. Whatever may be the cause (for at present it is not definitely known) such cases are an exception and not the rule.

Berlepsch (3) says that although the queen knows when to fertilise the eggs which she lays in worker cells, and when to lay them unfertilised in drone cells, if she is only provided with drone comb she will still lay in them fertilised eggs. This we have had ample opportunities of verifying, and more particularly at the apiary of Dr. Bianchetti of Ornavasso, described on page 58 of *British Bee Journal* for 1886.

Spermatozoa have considerable power of persistent vitality, and retain their functions for a long time stored up in the spermatheca—even resisting considerable deviation from the normal temperature; but prolonged exposure to cold has been found to destroy this vitality.

Dr. Dzierzon (37) found that a queen which had been frozen for a long time, after being again brought

to life by warmth, only laid male eggs, whilst previously she had also laid female eggs. Berlepsch (3) referring to this experiment, says he repeated it, and placed three queens for thirty-six hours in an ice-house. Two died, and one recovered, laying as before thousands of eggs—'but,' he says, 'from all of them only males were evolved.'

Sometimes, although spermatozoa are found in the spermatheca, the queen is still for some reason unable to fertilise the eggs. This may occur, as Leuckart (93) pointed out, from paralysis of the muscles, preventing them from acting in opening and closing the duct, or the duct may itself be injured, or from a lesion of the last ganglion, and Dönhoff (31) produced the same effect on two queens by pinching the abdominal segments with a pair of pliers. Both laid, but only drones were produced, owing to lesion of the nervous system. Leuckart made a microscopic examination of one of these queens, and found the spermathecal duct injured. He was the first to 'discover that a queen might be furnished with spermatozoa and be yet incapable of fertilising her eggs.' To this state he gave the name of '*arrenotokia*' (*Bienenzeitung*, 1855, and *Bull. Acad. Royale de Belgique*, 1857).

We have ourselves dissected several queens in this condition, and can fully confirm Leuckart's observations.

It will be noticed that there is a great similarity between the organs of the drone and those of the queen, and, as Leuckart has pointed out,

the different parts are homologues the one of the other.

Queens frequently differ in prolificness, which is often attributable to imperfect fecundation. A weak drone, as we have seen on page 133, could not fill the spermatheca properly, and this would render the queen less prolific. It will therefore be seen that great importance should be attached to rearing good drones as well as good queens, and, that these should be properly fed in their larval state, they must be reared in strong colonies.

In the worker, as a rule, the ovaries exist in a very rudimentary state (Fig. 55, C), and are sterile. They were discovered by Mademoiselle Jurine (75), and fully described by Ratzeburg (138) in 1833. They consist of a few thread-like tubes, generally from two to twelve, which contain no eggs, or even egg germs. At Fig. 55, C, *d*, is seen the rudimentary spermatheca, and the vagina is very narrow, and as the side pockets do not exist at all, it would be impossible for the male organ to enter it.

All bee-keepers know that occasionally a worker will be found laying eggs, and such an one is called a *fertile worker*. The ovarian tubes (Fig. 55, B, *a*, *a*) of a fertile worker, according to Leuckart, have the same structure as those of a queen, and, although never so long as these, are a little longer than those of an ordinary worker (*Bienenzeitung*, 1857). The oviducts and vagina are very much smaller, there is only a vestige of an appendicular gland (*d*), and the spermatheca and bursa copu-

latrix are entirely absent. It is evident such eggs, if laid, can only produce drones, as they cannot be fertilised, and this is in fact found to be the case. The question may naturally be asked, why these workers lay, and why their ovaries are more developed than those of other workers? Leuckart discovered (*Bienenzeitung*, 1855, p. 209) that the larva of a worker was weaned after it had left the egg three days, and as we have seen on page 120, the food underwent a change, whereas the queen larva received abundantly the same food during the whole of her existence, which he called royal jelly. He also found that it is exactly at the time of the change of the larval food that the female genital organs make their appearance, which will remain rudimentary or develop according to the food administered. If, therefore, weaning does not take place at the right time, any excess of royal food will develop the ovaries in proportion, and thus produce a fertile worker, which cannot mate, and can consequently only lay eggs producing males.

The discovery is attributed to Schirach (146) that if the bees lose a queen they are able to raise one from a worker larva, and for doing this they select one usually not more than three days old, when, by enlarging the cell and feeding more abundantly on special food, as we have described in Chapter xviii., the desired object is attained.

In artificial queen-rearing, we have always insisted on having queens started from the egg, so that they might have an abundance of proper food administered

to them from the first, as experience has taught us that such queens are much more prolific and vigorous. The explanation we have now given shows us the reason why this is so. Sometimes bees will start queen cells with larvæ over three days old; but these never can be so good, because weaning has commenced and the development of the ovaries has been retarded.

CHAPTER XXII.

METAMORPHOSIS.

Development of Embryo—Micropyle—Chorion—Vitellus and Blastoderm—Amnion—Ectoderm and Mesoderm—Nervous System — Ganglia — Tracheæ and Spiracles — Alimentary Tract—Dorsal Vessel—Appendages—Apodal Larva—Moulting — Spinning Cocoon — Transformations — Ganglia in Various Stages of Development—Blind Intestine in Larva—Wings—Silk Glands—Appearance of Egg Germs—Period of Rest.

BEFORE we proceed to describe the various changes the bee goes through from the time it leaves the egg as a tiny grub to the time it emerges from the cell as a perfect insect, which are called *metamorphosis*, it will be well for us to briefly explain the various stages of development of the embryo within the egg itself from the moment of its fertilisation. The subject has been investigated by Tichomiroff (162), Kowalewski (80), Bütschli (18); and in 1883 and 1884 Dr. Grassi (56) published his excellent and elaborate memoirs, in which he goes very minutely into the subject. The labour of this work may be estimated when we state that each egg was cut into no less than eighty sections to arrive at a proper construction. As the fresh egg is very transparent, he was able in every case to compare it with the sections taken from eggs of the same age.

The egg as laid, is an ovoid cylinder (Fig. 57, A), rounded at each end; the upper one, *n* (which at a later period contains the head of the larva) is the larger of the

two, more rounded, and in it is found the micropyle (centre of D). One face (*d*), the future ventral surface, is convex, the other (*e*) concave. The shell, or chorion, which is very thin, is covered with a delicate hexagonal network (Fig. 57, E). The egg consists of *vitellus* (yolk), in which no nucleus is visible (Fig. 57, A, *c*). Soon at each end of the egg, and at the anterior pole two cells are seen. These are followed by four, and so on, all remaining united, and giving rise

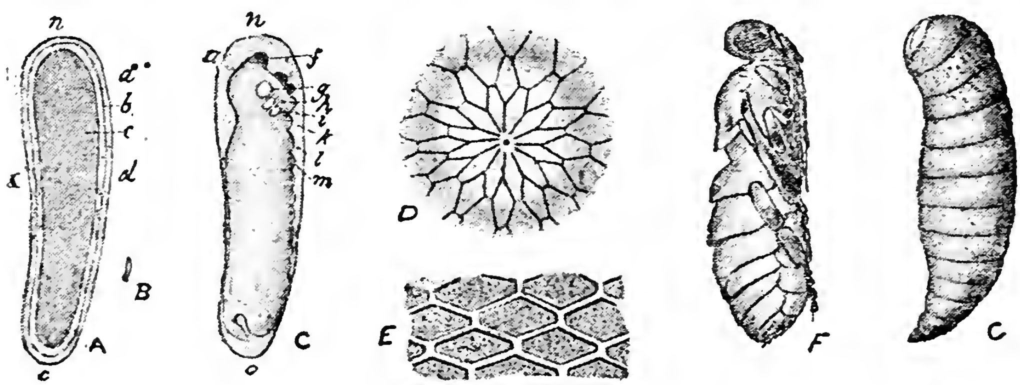


Fig. 57.—Development of Bee.

to the germinal membrane, called *blastoderm*, from which the embryo is developed. The cells on the dorsal surface soon disappear, and leave the vitellus, which consists of oily globules, uncovered over a certain area. Then from the cells is formed what is called the *amnion*, and ventral plate. After that the germinal layers appear, during the formation of which the edges of the amnion meet over the embryo and coalesce. The ventral plates become thickened and stratified, the superficial layer (*ectoderm*) becomes separated from the deeper layer (*mesoderm*), and is gradually folded on to the dorsal surface, the anterior and posterior portions approach, and ultimately

meet, while the embryo is becoming shorter as the ventral plate curves more and more to the dorsal surface.

The nervous system is developed rather late, and appears about the same time as the spiracles. The cerebral ganglia are formed as two thickenings of the ectoderm, appear about the same time as the antennæ, and do not become united until late in the development of the embryo. The ventral chain arises as two longitudinal swellings, which are at first quite separate, the ectoderm being also concerned in its formation. From this at a later stage also proceed the transverse commissures. The ganglionic chain of the thorax and abdomen consists of thirteen ganglia, and is prolonged into the head, where three ganglia appear, but are distinctly separated from each other.

Of the tracheal system, ten pairs of spiracles are the first to appear before the limbs show themselves, and after the amnion is a complete sac. The anterior ones appear first, and the invaginated ectoderm, which gives rise to the spiracle, grows inwards, and divides into an anterior and a posterior branch. Each ring, which is now visible, has one pair, except the first ring of the thorax and the two last abdominal ones, in which the spiracles are absent. The lateral tracheal trunk is united to its fellow on the other side, above the œsophagus, and also above the rectum. The spiral filaments (page 52) appear later. The tracheæ are filled with liquid, and air only enters them when the larva emerges from the egg.

Part of the alimentary tract, which is blind, appears

with the tracheæ, the remainder comes later. The former has a pit just behind the procephalic prominence, and in the posterior region of the dorsal surface two pair of small pits are found, which give rise to the four malpighian tubes. The rectum is at first a simple depression, which extends backwards, and forms a canal. Just behind the point where the second maxillæ will be formed, two fossæ appear (Fig. 57, C, *h*, *i*), which are directed backwards, and these are the silk glands. Two other pair of organs are formed as invaginations of the ectoderm, just in front of the mandibles (C, *g*), and on the third day the first pair disappear. The yolk begins to disappear in parts, and becomes concentrated round the future stomach, which then forms a cavity. The dorsal vessel is formed along the line where the two layers of the mesoderm meet dorsally. Later, and a little before the larva leaves the egg, the tube commences to enlarge, and contains blood corpuscles. Two solid cords of cells, unconnected with each other, extend from the fourth to the eighth abdominal segments, and give rise to the genital organs; at a later period they, however, precede the development of the muscles. The stomach is lined with ectoderm, the sides bending round and meeting on the ventral surface to form a tube. The procephalic lobe bends downwards towards the third day, so as to form the upper lip (Fig. 57, C, *f*). The antennæ, which grow nearly to the third day, appear simultaneously with the buccal appendages. Of these there are four pair, of which the first pair totally disappear, while the rest form the

mandibles (above *g*), and the other mouth parts. After these the three pair of legs are developed in succession on the thorax, which also disappear on the third day. Usually on the third day (although depending upon temperature and sometimes delayed), the chorion of the egg breaks, and an apodal (footless) larva, with thirteen segments, bends and straightens itself alternately to get rid of the egg envelope. It lies at the base of the cell, slightly curved (Fig. 1, D), and as it grows forms a complete ring, then, when it has no longer room for this position, its head is raised above its body, and it assumes a vertical posture. The food (prepared as we have seen in Chapter xvii.) is given sparingly by the nurse bees, and is the same the first three days, during which time the larva absorbs it by the mouth, and likewise by that portion of the body floating in it. It is assimilated in such a manner that the larva passes no dejections. After three days the food is changed, and now honey and digested pollen are by degrees added for those intended as workers; but those intended for queens are fed abundantly with the same kind of food during the whole of their larval existence. The drones are also weaned after the fourth day by having undigested pollen, as well as honey, added to their food. It is a curious fact, as we have already pointed out above, that before hatching the larva presents rudimentary legs, which some suppose to indicate *atavism* to an ancestral type of hexapodal larvæ; but M. Balbiani (48) has shown this to be incorrect, as in the flea the same thing takes place,

and the legs disappear. The larva (Fig. 57, G) is white, with a head slightly coloured, and having two little darker points for eyes. When the larvæ have grown to their full size after several moults, feeding ceases, the cells are sealed over, the cocoon is spun by means of the silk proceeding from the silk glands, which later change to the salivary glands (systems II. and III.) in the mature insect. After the cocoon is completed, which generally takes about thirty-six hours for the worker and twenty-four for the queen, the larva rests for a time, and then gradually changes into a chrysalis, or nymph. Now wonderful transformations take place. The mouth organs begin to form; the head, at first embedded in the thorax, separates; the constriction between head and thorax becomes more pronounced, and another constriction is formed between the thorax and abdomen. Little prominences appear gradually, forming the legs, antennæ, and tongue, which is extended along the body (Fig. 57, F). The wings also, at first hardly visible, folded round the thorax towards the legs, and the rudiments of the sting and male organs in the drone make their appearance. The compound eyes are white at first, but soon all the organs begin to acquire colour. The abdomen takes its shape, and in the queen and worker carries the sting at the extremity, at first on the outside. Then the whole body begins to colour, and the anal segments turn in to the preceding ones, so that the sting is now placed inside. Swammerdam (158) and Newport have very graphically described all these transformations.

But these are not all the marvellous changes which take place. The cranium ceases to grow in the larva before it changes to a chrysalis, while the segments of the body still continue to increase in size. The parts which are to form the head of the future nymph continue to grow beneath the unyielding cranium, from which, as the change approaches, they become detached, are developed backwards, and encroach upon the anterior portion of the first segment, the parts in the immediate vicinity being arrested in their development. This segment constitutes the atrophied pro-thorax of the insect, and is the first after the head. But at the same time it is encroached upon by the second from behind, the meso-thorax, which supports the organs of flight. The third segment from the same cause is developed backwards, and the fourth, reduced to a very small size, exists only as the petiole, which connects the thorax with the abdomen. The fifth segment is the first true one of the abdominal region, and the last three are fused into one, leaving three segments for the thorax and six for the abdomen, out of the original thirteen. In the drone there is an additional segment. While this is going on internal changes take place. In the larva the spiracles are simple, and there are eleven on each side (Girdwoyn, 49). In the pupa the tracheæ develop in great numbers, and as Leydig and Weismann (168) have shown, they are formed by invagination, and at the time of casting the skin the tubes are thrown off with it. The silk glands disappear, and others destined for other purposes take their place.

The embryonic larva has seventeen ganglia (Fig. 58, *A*), one supra-œsophageal (or cervical), three small sub-œsophageal (*H*), which later fuse into one, as seen at *B*, *C*, three thoracic (*T*), and ten abdominal (*Ab*), of which, according to Brandt (10), three unite and form the last but one abdominal ganglion in the larva, which then has only eight abdominal ganglia. When the chrysalis stage is reached the second and third thoracic and the first and second abdominal ganglia coalesce into a single nerve mass (*d*, C). Other ganglia also coalesce, so that in the adult stage, *C*, the worker has five abdominal ganglia, and the drone and queen only four (Brandt).

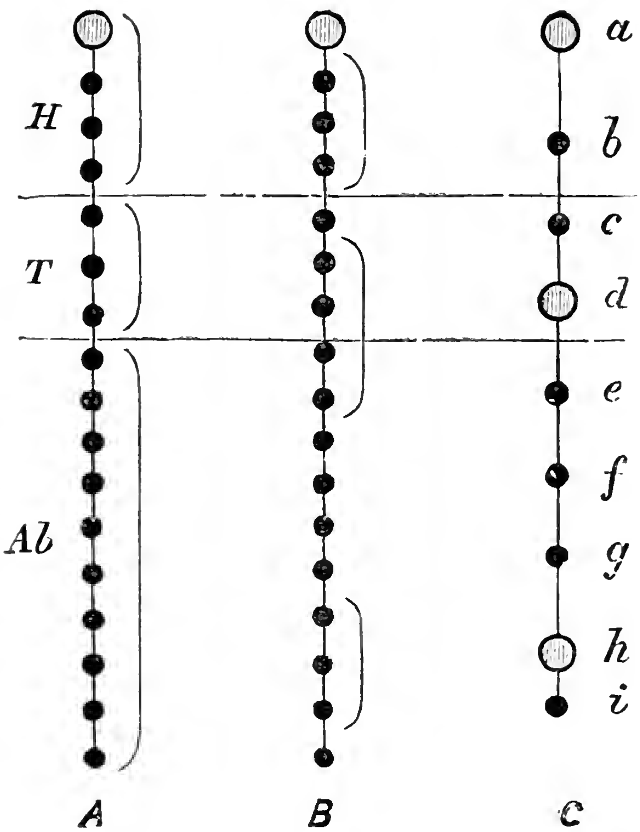


Fig. 58.—Diagram showing Ganglia in various Stages of Development.

Fig. 58 is a diagram showing the different stages, *H*, representing the head, *T*, thorax, and *Ab* abdomen. The brackets in diagram *B* show the various ganglia that coalesce: *C* represents the ganglia in the adult stage of a worker.

Girard (48) says that embryogeny shows the digestive tube of insects to be formed in three parts—

the mouth and anal extremities by invagination of the external skin (Fig. 57, c), the yolk separating the anterior and posterior portions of the intestine. The middle or central portion fôrms the yolk sac, and later the separating walls undergo absorption, forming a single and united tube. The annexed organs are then added to this intestine, which forms prolongations of the wall. In this manner the salivary glands are also formed from the silk glands in the larva at the anterior part, and at the posterior the malpighian tubes, or urinary organs. An arrested development in the larvæ of bees, hornets, and wasps, causes the middle intestine to remain blind, so that the larva in the cell passes no dejections, which were it otherwise, under the conditions of its existence, would be an embarrassment. The manner in which the bowel is cast has been explained in Chapter ii., page 11.

As the abdomen acquires its shape, the sting, as we have already seen, first outside, becomes internal on the infolding of the anal region, and at the same time new muscles and tendons are formed.

The development of the wings has occupied the attention of many scientists, amongst whom we may mention Swammerdam (158), Burmeister (17), Pancritius (122), Landois (87), Girard (47), Rehberg (141), and others. Girard says the wing is formed from a vesicle, or flattened pouch, supported in the interior by a framework of tubes of chitine, which form the nervures; when, by re-absorption of the contained fluid, the two membranes are intimately joined, they

become transparent membranes of the wing. The nervures are hollow, and through them run tracheæ, for it is the air contained in them which assists in the expansion of the wings, still soft when the adult bee leaves the cell. Blood surrounds these tracheæ during the period of development of the wings.

The development of the silk glands was specially studied by Schiemenz (144) in 1883. Portions of these glands are shown in Fig. 59. They are situated on each side of the alimentary canal, and are in the shape of spiral tubes, which unite in the head, continuing as a single tube, having its outlet at a conical papilla in the under lip.

There are two distinct structures in these glands: the one found in the anterior portion from the outlet, is shown in section at C, Fig. 59, and the other as in section

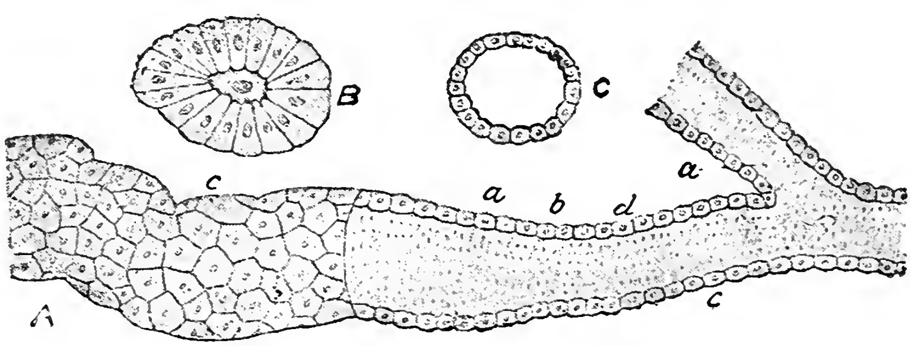


Fig. 59.—Silk Glands.

B, is continued to the blind extremities of the glands. The anterior portion (C) is a reservoir, whose intima, the continuation of the epidermis, is surrounded by a cell layer, which thickens towards the blind ends, and the cells then take the form shown in Fig. 59, B, surrounding

a small tube, or lumen. This is the glandular part, and the secretion is derived from the blood by absorption through the surface of the cells on the outside (Fig. 59, A, *c*), while the inner surface secretes a liquid silk, which fills the lumen, and is collected in the reservoir of the larva of four and five days old, before the time of spinning. At a later stage, when the spinning is done, the secreting portion of the gland shrinks, and from the inside of the propria is gradually built up, first the gland, System III. in the adult, and later System II.

We have already seen that the drone organs are highly developed at a very early stage in the pupa, the testes being of an enormous size. Although egg germs are later in making their appearance, Leuckart found the first traces of the internal genital organs in female larvæ six days after the laying of the egg, and that at exactly this time the change of food takes place in the worker larvæ. Those intended for queens receive the same food, which rapidly develops the ovaries, whilst the change of food in the worker larvæ stops their development, hence we only have the rudimentary ovaries, already alluded to.

The period of rest after spinning the cocoon varies, that of the worker being two to three days, drone four days, and the queen only two. The time of feeding the larva is generally five days for queen and worker, and six days for the drone. The time occupied in the changes from the time the egg is laid to the time the perfect bee is ready to leave the cell is about fifteen days for the queen, twenty-one days for a

worker, and twenty-four days for a drone, although these periods may vary considerably, as Berlepsch (3) has shown; and every observant bee-keeper must have noticed that the hatching is frequently delayed beyond these periods.

CHAPTER XXIII.

HERMAPHRODITE BEES.

Abnormal Bees—Frequent Occurrence—When First Observed—Peculiar Characteristics—Combination of Sexual Characters—Imperfect Fecundation—Imperfect Nutrition—Cyclopie—Albino Bees.

ALTHOUGH we have seen that an impregnated queen is capable of fecundating the eggs, and producing females and males at will, it sometimes happens that abnormal bees are found in a hive, having parts common to the two sexes in one individual. Such cases occur much more frequently than is generally supposed, and they were first observed by Lucas (103) in 1808. Since that time they have frequently been mentioned and have been studied and described by Dönhoff (*Bienenzeitung*, 1860), Siebold (*Bienenzeitung*, 1865), Leuckart (*Bienenzeitung*, 1866), Berlepsch (3), Assmuss (*Bienenzeitung*, 1866), and others. Girard (48) says they are very frequent in some hives, some with worker head and thorax and drone abdomen and male genital organs; also drones with sting and poison glands more or less developed. Siebold, who made careful dissections of them, found a combination of their sexual characters, therefore he called them *hermaphrodites*. The development of the internal organs was co-related with the peculiarities of the external. In those with worker abdomen, he found the spermatheca and ovaries present, but empty, the sting with

its vesicle and glands being well developed. In those with a drone abdomen, the male sexual organs were well developed, the testes containing spermatozoa; the ovarian organs, sting and poison apparatus, were in an imperfect state. He ascribes the production of them to imperfect fecundation of the egg.

Mr. Dodge* relates that amongst others reared in worker cells, he had some with drone abdomen and thorax, with a worker head; worker abdomen and thorax with drone head; drone abdomen and thorax with one half of the head worker, the other half drone; and worker abdomen and thorax with half worker head and half drone.

Berlepsch (3) also mentions a number of similar and other cases, and states their cause to be the partial fertilisation of the egg, either from a defect in the micropyle or disease of the spermatozoa; or that these are not able to properly penetrate the vitellus; or that they are not properly developed, and have not the power to completely form the sex.

We believe that nutrition has much to do with bringing about such cases, and as we have seen that bees do vary the food of the larva according to their several requirements, it is not difficult to understand how an improper administration of this food may result in an abnormal differentiation of the sexes such as we have described.

Lucas (103) also mentions a curious case in a worker, where the two eyes were fused into one, without any division (Fig. 60), which he calls *cyclopie*.

* *American Bee Journal*, Vol. XV.

Besides these there are Albino bees. We have two bottles before us now, containing about 100 drones, taken from the same hive in 1885 and 1886, in which every drone has both compound and simple eyes white: presented to us by our friend, M. Bertrand. These are not at all uncommon, and are mentioned by Berlepsch (3), Vogel (166), and others. Girard (48) also mentions having seen them at the apiary of M. Drory at Bordeaux.

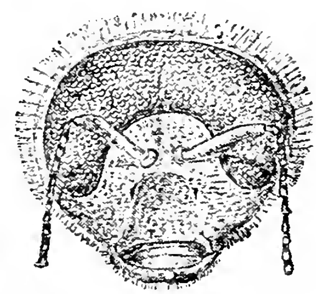


Fig. 60.—Cyclopie.

Major v. Munn described them (*Bienenzeitung*, 1886), and stated that if placed in a box they crawled out, walked on the table, and fell on the floor, but evidently could not see, as they did not fly to the window. Vogel, who examined them microscopically, found the eyes quite transparent and destitute of pigment. The hairs and simple eyes were also quite white. We have had many similar drones sent to us as curiosities.

Vogel also relates that on one occasion he had a worker bee which was perfectly white all over.

CHAPTER XXIV.

WAX AND COMB CONSTRUCTION.

Thorley's Views—Martin John—Willelmi and the Lusatian Peasant—Wax Scales—Hunter and Huber—Wax Discs—Glands—Fluid Wax—Wax Pockets—Secretion of Wax Voluntary—Huber's Experiments—Wax produced from Saccharine Substances—Dumas and Milne-Edwards—Pollen required—Quantity of Honey required to produce Wax—Action of Swarm—Festoons of Bees—Construction of Comb—Cells at first Circular—Tegetmeier's Experiment—Reason of Hexagonal Cells—Irregularity of Cells—Experiments and Measurements on different Combs—Irregularities in Worker Cells—Causes which produce them—Variation in Bases of Cells—Improper Alignment—Inclination of Rows of Cells—Attachment—Square and Transition Cells—Variation of Angles—Scooping Action—Queen Cells—Colour of Wax derived from Pollen—Composition—Specific Gravity—Coverings of Cells—Conclusion.

OF all the discoveries in connexion with the honey bee will always be reckoned amongst the most important and interesting that of the production of wax.

Although the discovery is usually attributed to a Lusatian peasant, Thorley (161) mentions it in 1744 in the following words :

'For several seasons after I become a Bee-master, I was very desirous and diligent to find out how, or where, they brought home their wax, well knowing that gross Matter to be of a very contrary Nature, and applied to some other Use, but was not able for a considerable Time to enter into the secret.

'At last, viewing a Hive of Bees very busy at Labour, I

observed one Bee among the rest, as she fixed upon the alighting Place, of an unusual appearance ; upon which I seized her directly, before she had time to enter the hive ; where, with a sensible Pleasure, I found what I had (till then) been in vain searching for. Upon the Belly of this Bee, within the Plaits, were fixed no less than six pieces of solid Wax, perfectly white and transparent, like Gum ; three upon one side and three upon the other, appearing to the eye equal in Bulk and Gravity ; so that the Body of the Bee seemed duly poised, and the Flight not in the least obstructed by any Irregularities. Here have I found it at other Times, and once I took away eight Pieces together, and I know that it was Wax, and nothing else. Will not this pass for Demonstration ?'

This discovery does not seem to have been generally known, nor that Martin John (74) had in 1684 made a similar discovery, for on 22nd August, 1768, M. Willelmi wrote to M. C. Bonnet (8) to say that a German peasant, member of a society of bee-keepers, had made the discovery that wax was produced between certain of the rings on the under side of the abdomen (Fig. 61), in the shape of scales. Unfortunately, M. Willelmi does not mention the name of this Lusatian peasant, but states that the wax scales can be removed with the point of a needle from a bee working at comb building. Subsequently, Hunter (69), in 1792, drew attention to the wax glands, and Huber (68), in 1793, commenced a series of experiments, which confirmed the discovery, showing that wax was produced from honey, and not gathered, as was supposed by Réaumur (139) and others.

We have already seen (page 48) that on the four

ventral plates (Fig. 22, *c*, *d*, *e*, *f*) there is a framework of chitine surrounding two transparent surfaces. One of the ventral plates is shown enlarged at Fig. 62, which is taken from a photo-micrograph, and shows the transparent surfaces (*b b*) on which the wax scales are produced. The dark part shows the hard chitine framework surrounding the discs, with the division (*a*) called the *septem*, or *carina*. The transparent wax-yielding surfaces are irregular, pentagonal in shape, and are covered by the segment immediately above them. The lower part, which overlaps the plate below it, is of hard chitine, and covered with feathered hairs (*c*). The smooth

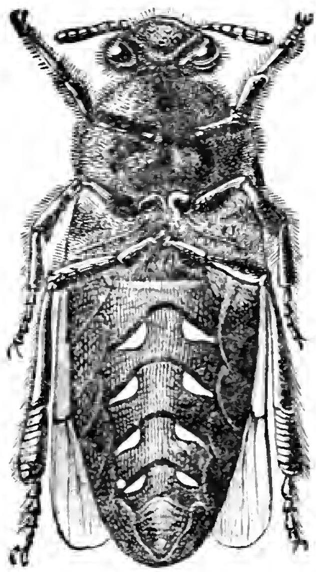


Fig. 61.
Wax Scales.

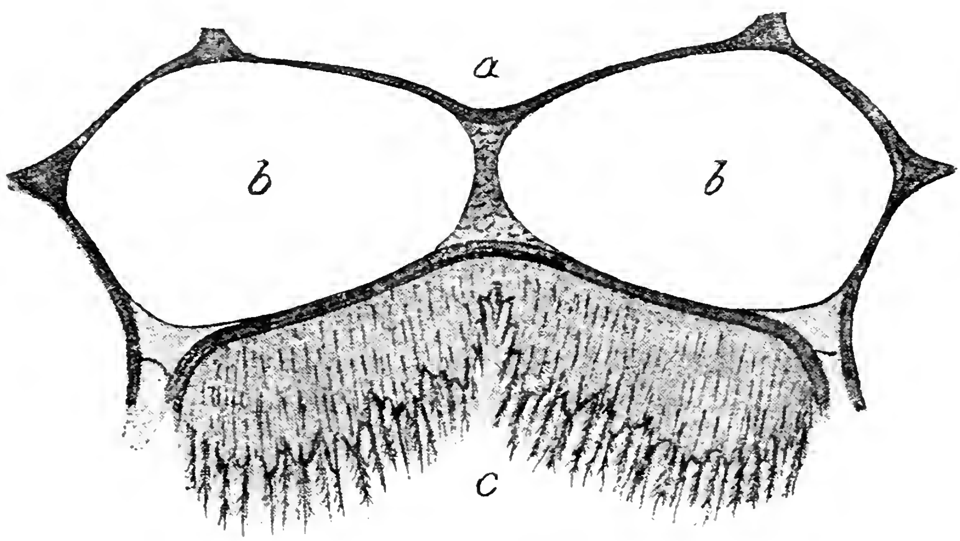


Fig. 62.—Ventral Plate of Worker.

surfaces are slightly sunk, and are the moulds on which the wax scales are formed from the secretion

which, as Latreille (90) has shown, passes through them in a liquid state, from glands situated beneath. In the queen and drone these discs are absent, and in the former, although the plates are broad, the hairs are very short, while the latter has a few stout feathered hairs and narrower plates.

The wax-secreting glands (six-sided cells containing granules and a nucleus) are only found immediately under the transparent membrane, and do not exist beyond the framework.

H. Holz, who describes and illustrates them in *Bienenzeitung* for 1878, says the fat cells are connected with the membrane by tubes, through which the liquid wax flows to the membrane, and passes through this when the temperature is at 95° to 98° Fahr.

Latreille (90) has also pointed out that the transparent surfaces are made up of an outer and inner layer, the epidermis and hypodermis. A soft tissue formed by infiltration from secretion within is found between these two layers. Blanchard also found that the wax which was formed by glands inside the abdomen, passed through the transparent membrane.

The fluid wax is moulded on the depressed cavities; the hard part of the segment above, pressing over them, causes the liquid wax to assume their shape, and the little scales (Fig. 63, A), when they become solid, are drawn out of these *wax pockets*, as they are usually called.

Wax is not produced at all times, but its secretion is voluntary, and for its production a temperature of from 87° to 98° Fahr. is required, which the bees are

able to obtain by close clustering. The wax scales resemble mica, are transparent, very brittle, of a pale yellow, and during comb building they stand out beneath the segments, as seen in Fig. 61. They are removed by the pincers on the hind legs described on page 36, the bristles piercing the scale (Fig. 63, A), and are then transferred to the front legs, and at last to the mouth, to be masticated by the jaws (Fig. 63, B), with the addition of saliva, which modifies the wax and makes it malleable. Dr. de Planta* found

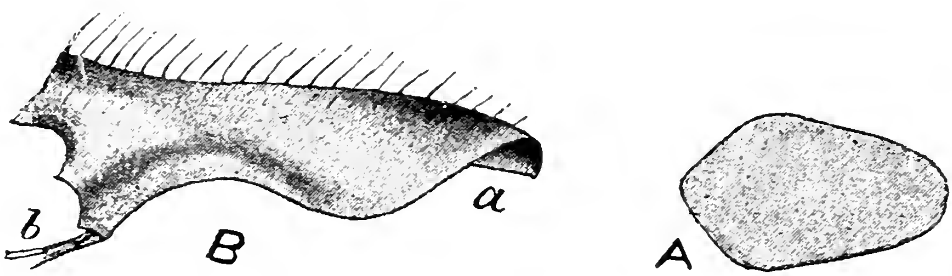


Fig. 63.—Jaw of Worker and Wax Scale.

that a considerable quantity of saliva entered into the composition of wax used for making the combs which he did not find in the scales.

Huber carried out a series of experiments, which he repeated several times, with the result that he found, that bees fed on honey and water produced wax, while if only fed on pollen, none was produced. He also showed that bees fed on sugar syrup were also able to produce wax, and that in several consecutive trials those receiving syrup made of sugar yielded more wax than those fed on honey, brown moist sugar yielding the largest quantities. These results were

* *British Bee Journal*, 1883, p. 267.

fully corroborated by Dumas and Milne-Edwards (35), who in 1844 repeated Huber's experiments, and found that 500 grammes of sugar yielded 30 grammes of wax, whilst the same quantity of honey only gave 20 grammes. Other observers, such as Gundelach and Berlepsch, have obtained similar results, so that Huber's statements may be considered as established.

Although honey or saccharine matter is only needed, Berlepsch and others have pointed out that bees cannot do without pollen, to make up for the enormous wear and tear of tissue caused by wax secretion, so that in an indirect way it assists in its production, and they cannot continue secreting wax for a long time without it. The exact amount of honey consumed in producing a given quantity of wax is not yet decided, and scientists differ in their opinions.

Experiments were carried out by Gundelach (60), Berlepsch (3), and Dönhoff (31), with variable results from the different methods adopted and the difficulty of the trials.

Gundelach found that it required 17 lbs. of honey to produce 1 lb. of wax when bees had no pollen, whereas Berlepsch states they took from 16 to 19 lbs. to produce the same quantity of wax under the same circumstances. Fed on sugar without pollen, 16 lbs. produced 1 lb. When they had both honey and pollen, 10 lbs. only were required for 1 lb. of the wax, while Dönhoff arrived at 12 to 21 lbs. under similar conditions. Recent experiments of M. J. de Layens*

* *Bulletin d'Apiculture pour la Suisse Romande*, 1886, p. 215.

have shown that 6·3 grammes of honey were consumed in the production of 1 gramme of wax.

When a swarm is placed in an empty hive, the bees suspend themselves from the roof in such a way as to form festoons (Fig. 64). The first clings to the top by means of the claws on the front legs, the second hooks herself on to the hind legs of the first, and so

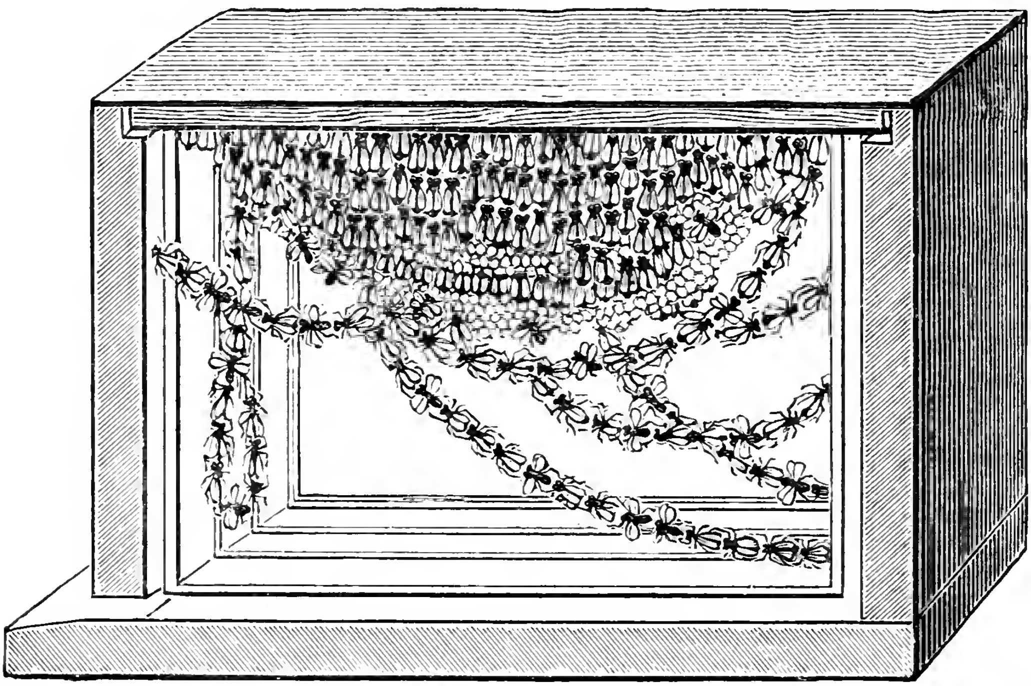


Fig. 64.—Festoons of Bees at Work.

on. In this manner they form chains fixed by the two ends to the roof, which serve as bridges or ladders for the bees. The result of these festoons is a cluster of bees, which hangs down to the bottom of the hive. In this attitude they remain motionless and sustain a high temperature, while the honey is converted into wax and exudes on the surface of the wax pockets. When the wax is in a suitable condition, one of the bees detaches herself from the cluster, and having

prepared the wax by making it plastic with saliva, as already described, sticks it to the roof. To this first layer others are added, till all her wax is exhausted. Other bees do the same thing, and continue laying the foundation. Presently, small, shapeless blocks of wax hang down from the roof. It is these blocks that the bees, with their mandibles, scoop out and form into the first cells, adding what is removed to the edges.

While the workers continue to prolong the foundation wall, and whilst the first cells are being shaped, new ones are set out, and the work advances with a marvellous rapidity.

Each cell forms a hexagonal cup, closed on one side only by a pyramidal base, produced by the meeting together of three rhombs, or lozenges. These form the midrib, the cells on the opposite side being similar, but so arranged that the base of each cell is formed by the union of the bases of three opposite cells.

The bees begin by scooping out the base of the cell with their mandibles, which by reference to Fig. 63, B, will be seen to be admirably adapted for this purpose.

The wax which is removed is placed on the edges. All the cells are commenced in the same way, as M. Tegetmeier (159) pointed out in his experiments. He says:

'My first experiment consisted in placing a flat, parallel-sided block of wax in a hive containing a recent swarm. In this the cells were excavated by the bees at irregular

distances. In every case where the excavation was isolated it was hemispherical, and the wax excavated was added at the margin, so as to constitute a cylindrical cell. As other excavations were made in contact with those previously formed, the cells became flat-sided, but from the irregularity of their arrangement not necessarily hexagonal.'

The actual manner in which the bees form the cells has been closely observed by Dr. K. Müllenhoff (112, 113), who has shown that mutual interference forms the hexagons, as all circles coming in contact with each other naturally assume this form. He alludes to the Buffon experiment with bottled peas, swollen into hexagonal form by mutual pressure, and also shows that the cells behave mutually like soap bubbles, which when isolated are round; but if touching each other, where united the film forms a perfectly flat wall. If there are many, those in the centre will be hexagonal, whilst those on the outside will have their free sides curved. Waterhouse (167) also called attention to this, and it can be seen by any observant bee-keeper, although still denied by some. The rhombs are formed in the same way, by two layers pressing in opposite directions.

It has been shown that the complexity and apparent accuracy of the structure is not in the least owing to the development of a mathematical instinct in bees, or artistic dexterity, but simply to physical laws dependent on their method of work, or as Müllenhoff puts it, to 'statical pressure according to the laws of equilibrium.'

The cells are hexagonal, and there is a very good reason for this form. Mathematicians have shown, as Dr. Reid (140) points out:

'There are only three possible figures of the cells, which can make them all equal and similar without any useless interstices. These are the equilateral triangle, the square, and the regular hexagon. It is well known to mathematicians that there is not a fourth way possible in which a plane may be cut into little spaces that shall be equal, similar, and regular, without leaving any interstices.'

The square and the triangle would be unsuitable, owing to their angles, for the round body of the chrysalis, which could only utilise the enclosed circle, but the hexagon is a nearer approach to this than either the square or triangle. The hexagon has also a smaller circumference than either of the other two figures, so that there would be an economy in material in constructing such cells. But there is also an economy of material in the bases, while best fitting them to the shape of the chrysalis. For if any other angle had been adopted, Lhuilier (97) pointed out much more wax would have been required, and if the midrib had been flat he calculated that as much wax would be required to construct fifty cells as it takes to make fifty-one with pyramidal bases. It is known that Maraldi (106) had studied the form of the cells of the bee, and had described the angles of the rhomb, as well as Réaumur (139), who did so at a later date; and it is part of the history of the subject that Kœnig's results, to whom the problem was submitted for solution, differed from those of Maraldi by

two minutes. We have not room here for the whole history, but we would point out that, even with our accurate instruments of the present day, it is impossible to measure the angles of such a structure as the cell of a bee without liability to error of one or two degrees in each angle, since the angle of the cell is nowhere sharply defined, and the surfaces are not strictly planes. Father Boscowich seems to have been the first person to call in question Maraldi's measurements, and 'supposed that the admeasurement of the angles was too nice to be performed, and that the coincidence with the theory could only arise from his assuming that the angle of inclination of the rhomboidal plane was the same with that of the hexagon' (Lord Brougham, *Nat. Theol.*). Lord Brougham (15), however, says: 'I can certainly find no irregularity,' and further, 'The nearly quite (in reference to Lhuilier's criticisms, that the conditions required by theory and observation "nearly agree") is quite incorrect: there is an absolute and perfect agreement between theory and observation.'

Wyman (171) took a number of measurements, and says—

'If economy of space and wax is sought, that the form of cell should be the one alleged to have been ascertained by Maraldi, and which was calculated by Kœnig, and by hundreds of others since his time. Careful observations, however, tend to prove that such a cell is rarely, perhaps never, realised. For, while the deviations from the true form do not exceed a certain limit, a piece of comb, ten cells square, can hardly be found in which one or more

irregularities do not occur of such magnitude that however they may look to the bee's eye can be readily detected by man's.'

The best observers, such as Réaumur (139), Huber (68), Hunter (69), and others, have noticed some of these, although they passed them by with merely a mention.

Being much interested in the subject, and in order to satisfy ourselves upon this point, we some years ago determined to carry out a series of measurements upon combs built naturally. We have also taken a large number of impressions of natural comb, which show with the greatest accuracy the shapes of the cells. The combs examined were those of black bees in England, Italian bees in Italy, and Carniolan bees in Switzerland; also various bees in Canada and the United States of America.

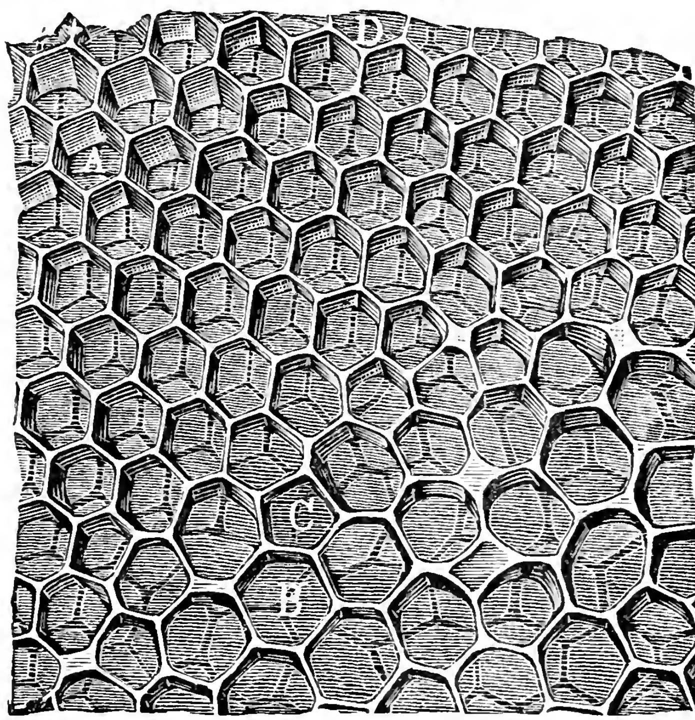


Fig. 65.—Comb with Various-sized Cells.

It would be impossible within the limits of this work to give all our experiments, so we shall content ourselves by giving a summary.

There are different kinds and sizes of cells in a hive.

The worker cells (Fig. 65, A, and Fig. 1, D) are $\frac{1}{5}$th of an inch between the parallel sides, and $\frac{13}{64}$ths of an inch across the angles. The drone cells (Fig. 65, B, and Fig. 1, K) are $\frac{1}{4}$th of an inch between the parallel sides, and $\frac{9}{32}$nds of an inch between the angles. According to Abbé Collin (26), there are 27·5 worker cells and 17·09 drone cells to a square inch of comb on each side, although, taking the average of a large surface, not more than 25 and 16 will be found, and these numbers have generally been adopted. The thickness of worker comb having two cells with one base between measures about $\frac{7}{8}$ths of an inch, that of drone comb being $1\frac{1}{4}$ of an inch. Besides these there are the queen cells (Fig. 1, F, G, H), and what are called transition cells (Fig. 65, C, and Fig. 1, L), attachment cells (*Heftzellen* of the Germans) (Fig. 1, M), and honey cells (Fig. 1, I), although both worker and drone, as well as transition cells, are used for storing honey. All these are built horizontally with an upward inclination towards the opening, and some are slightly curved, with the exception of the queen cells, which hang with their openings downwards.

The average size of a worker cell between the parallel sides is $\frac{1}{5}$th of an inch, or 0·02 (A, Fig. 65, which is taken from a natural comb). We say 'average,' because considerable variation exists in different parts of the same comb, as both Réaumur and Huber found. In carrying out our experiments, we took our measurements on three parts of each comb, and in each case in the three directions of the parallel sides. Thus, each comb furnished us with nine measurements. In order to reduce the possibility of

errors occurring from measuring only one cell, we selected ten cells, which, allowing $\frac{1}{5}$th of an inch to each cell, should occupy the space of 2 inches. In all, thirty-six measurements were taken, and we found the greatest aggregate diameters of any one series of ten cells to amount to 2·11 inches, and the least to 1·86, a difference of the diameters of a little more than a cell and a quarter. We next measured a large piece of comb, and took sixty cells, which theoretically ought to occupy the space of 12 inches. The measurements were made on three different combs, but they showed much variation. For instance, one row of cells taken 2 inches from the top measured 12·10 inches, and 4 inches from the top 12·00, and 2 inches lower down 12·01 inches. Taking ten cells in either of the above rows also showed considerable variation. In the first row the aggregate diameter of ten cells taken at one end was 2·07, in the middle 1·98, and at the other end 2·08. In the second row the diameters were 2·10, 1·95, and 1·98. In the third row 2·00, 1·95, and 2·05. From this it will be seen that the variation is not regular, but generally speaking the cells increase in size towards the ends, although this is not invariably the case. All these combs were worked by black bees in the natural way; but we would mention that measurements taken on combs worked by Carniolan bees showed the same variations, but the average size of their cells was larger.

The variation of the diameters is certainly not due to stretching, for in our first measurement we found the aggregate of sixty cells between the parallel sides

standing vertically, and which would be compressed if the comb were stretched downwards, was actually a little more than in the others, being 12·17, while the others were 12·10 and 11·58.

These, however, are not the only variations. There are much more remarkable ones in the bases of the cells. Huber (68) and Bevan (4) have pointed out some of them. These variations upset all the problems of the mathematicians with regard to this subject. The sizes of the rhombs may be so changed that two of them occupy nearly the whole space, while the third nearly disappears, and a fourth makes its appearance. The fourth face has often been attributed to cells which were intermediate between drone and worker, but it is also very common in the middle of both worker and drone combs. The causes of the introduction of the fourth face is owing to the variation in the size of the cells, or incorrect alignment of them on the two faces of the comb. If a cell is constructed as it should be, the edges of the three rhombs will come in contact with the sides of the cells, but if it is increased it must project beyond and come in contact with a fourth, which will form a new face. This sometimes happens in one cell, but more frequently in a series of from four to eight or nine.

The illustration (Fig. 66, A) shows the gradual introduction of the fourth face, and a complete change from *a* to *b* in six cells, whereas in the figure B the change from *c* to *d* is made in ten or eleven cells.

What we have said with regard to worker cells applies also to drone cells (B, Fig. 65), which are $\frac{1}{5}$th

larger. Fig. 66, C, shows a series of these where the change from *e* to *f* has taken place in seven cells.

But, besides this irregularity, due to improper alignment on both sides of the comb, there is another

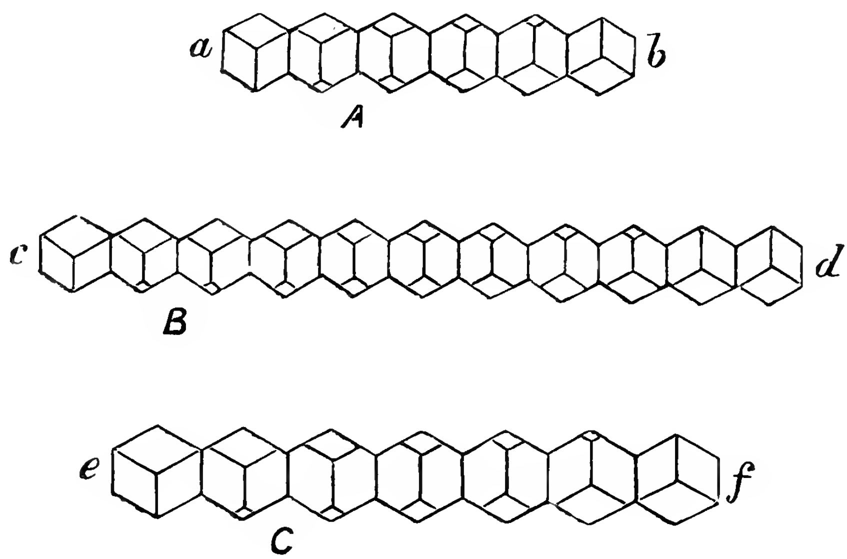


Fig. 66.—Variation in Bases of Cells.

which we have observed in drone comb, but never in worker comb, although Wyman (171) mentions an instance of its being found in this. Fig. 67 will explain this variation, the thick lines representing the cells on one side of the comb and the thin lines those on the other. In this case the pyramidal bases are impossible, and we therefore find them flat.

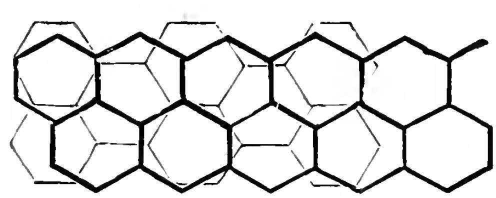


Fig. 67.—Variation in Drone Comb.

It has been generally asserted that bees begin by building rows of cells to the roof of hive or top bar, and continue these parallel. But this is by no means

always or usually the case. We have before us combs built by Carniolan bees, taken from a flat-topped skep, which was sent to us for the purpose of measurement. Of the nine combs, only one had the rows of cells parallel with the top; the others were all inclined, the slopes varying from 10° to 45°. Some of the combs had two different slopes; the left-hand half of one sloping 45°, while the right-hand side sloped only 15°. The next comb to this sloped 45° and 10°.

When combs are built regularly the cells are usually attached to the top by the two parallel sides (Fig. 68, A and B, *a*), so that the first row of cells,

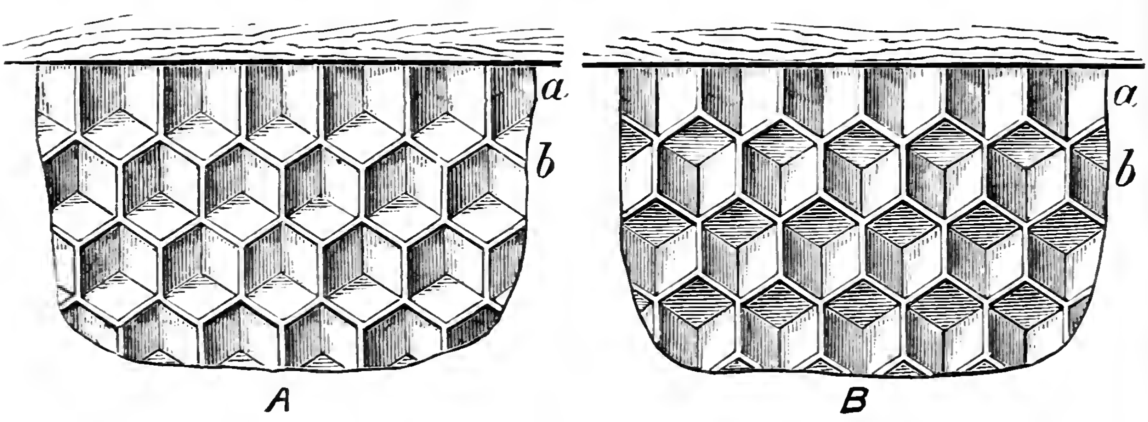


Fig. 68.—Attachment Cells.

called attachment cells, have only four sides of wax, the tops, or fifth sides, being formed by the surface to which the cells are attached. Fig. 68 shows a row of these attachment cells at *a;* those in A are on one side of the comb, the rhombs at their bases being visible, while those at B show the other sides of these cells without the rhombs, which on this side form part of the next row of cells, *b*.

When rows of cells are built at an inclination, the

top cells are elongated, and sometimes smaller cells are built to fill up. In one of the combs mentioned above, the first row of cells was turned with its parallel sides to the top, all the other rows following in the same direction. The rows were slightly curved, and were inclined over the whole comb from right to left at an angle of 43°.

To any one who carefully observes naturally built combs, the irregularity is most striking. Besides the small differences in size which we have mentioned, cells of different shapes frequently occur, and we have seen them with as few as three, and as many as seven sides. One of these is seen in Fig. 69, *a*, and another in Fig. 65, *c*.

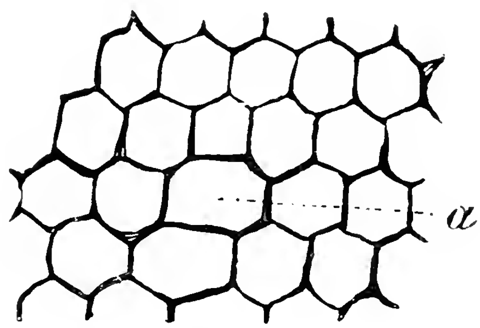


Fig. 69.—Irregular Cells.

The illustration (Fig. 70) shows cells nearly square. These are from a comb we obtained in Canada

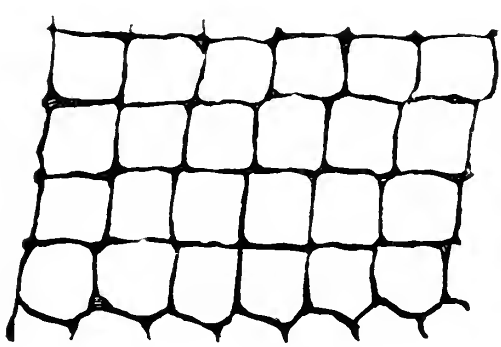


Fig. 70.—Square Cells.

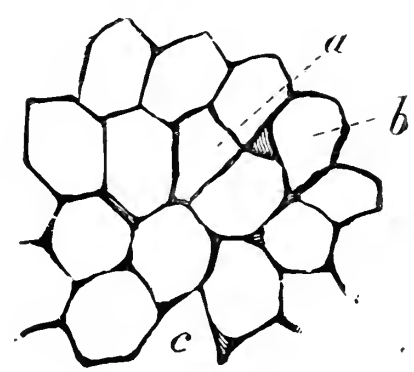


Fig. 71.—Cells with Acute Angles.

through the kindness of Mr. D. A. Jones. Several of the rows consisted of such square cells.

In the next illustration (Fig. 71) we see other forms of cells, some of them (*a*, *b*, *c*) having acute angles, which some allege it is impossible for bees to build, but which nevertheless they have done, as all these illustrations are engraved from impressions taken from the actual combs.

Besides the regular six-sided worker and drone cells, there are transition cells. These are constructed in passing from worker to drone cells. The alteration is made in from four to six rows, but sometimes, although very rarely, in one row. The transition cells are very irregular, and there seems to be no rule to guide the bees in their construction.

In Fig. 65 we see some of these cells at C, between the worker cells (A) and drone cells (B). In the illustration (Fig. 72) a number of such cells are shown, and the regularity of the comb is to a certain extent preserved by the intercalation of an additional row of cells, as it will be seen that the first four rows of drone cells at *a* on the right-hand top corner are equal to five worker cells (*b*) lower down. In the transition cells of brood combs, brood is frequently found. At *d* will be seen cells with right angles, and at *c* a cell having seven sides. The thick lines show where the walls are thickened, and the shaded parts where the spaces are not large enough for cells ; these are usually filled in with wax and excavated a little way down from the surface.

The angles between the cell wall vary considerably, as will be seen in the illustrations (Figs. 69, 71, and

72), where some of them are even less than a right angle, or 90°.

We took a number of measurements of some of the most regularly built combs with an accurate goniometer, and found that the angles varied several

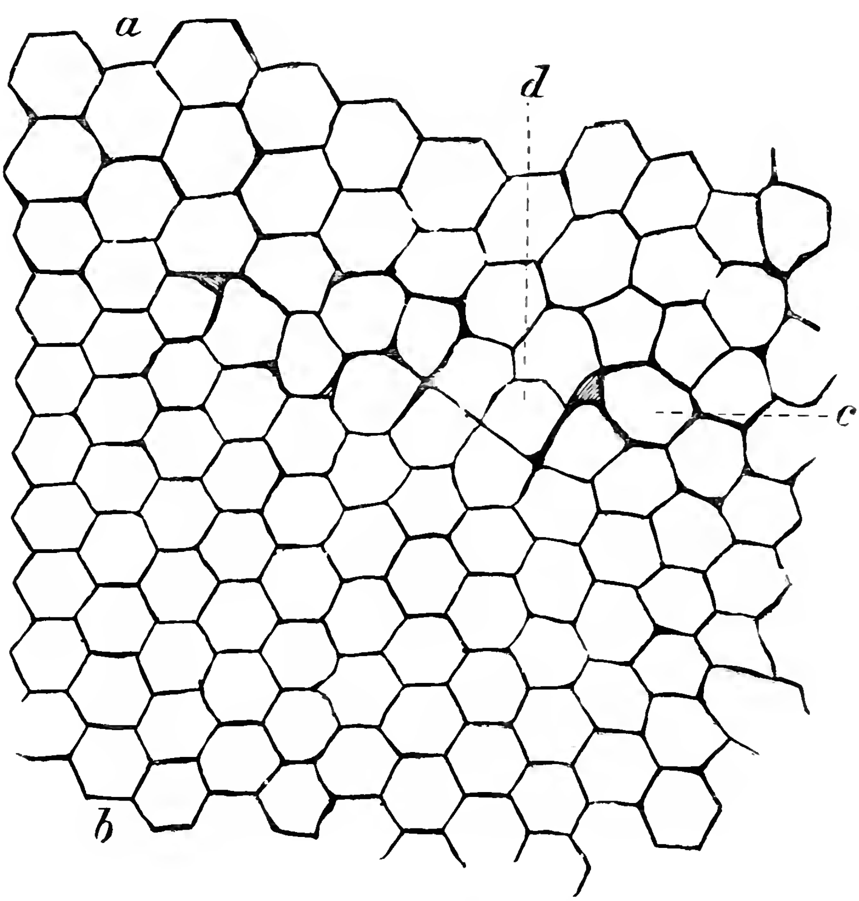


Fig. 72.—Transition Cells.

degrees. The normal angle which one side makes with the adjoining one is 120°, but we found some angles to be as large as 130°, while others were as small as 110°, even in regular combs.

All the cells we have described are used for storing honey, and frequently those which are specially built for this purpose vary considerably in depth.

When working bell glasses we have frequently had combs 2 to 3 inches thick. Sometimes the cells are square, or five-sided, and the alignment is rarely exact. The thickness of the walls also varies greatly, one being sometimes double the thickness of the next one to it. When honey cells are built on a curved dividing wall, the bees seem to make no attempt to correct the diverging or converging lines. In brood combs they do make an attempt to do so, and therefore fill up little cavities, such as we have shown (the dark places) in Fig. 72, with wax. But in honey cells sometimes the mouths of the cells are expanded to nearly double their diameter, and not infrequently two separate cells are merged into one when they reach half their length.

From the above it will be seen that although the bees may endeavour to arrive at a perfectly symmetrical cell, they hardly ever obtain one.

We have seen that bees commence on a base by scooping out the wax. This they do with their jaws (Fig. 63, B), which are hollowed out for the purpose. As the wax is scooped out it is put on the side walls, which are thereby thickened, and give the mouth of the cell a circular form, in all stages of its progress. Many cells are found into which a bee cannot enter, but as the wax is always added to the top edge she has only to work down inside a very little way, and we presume she does much in the same way that a bricklayer would do when building a chimney from the outside, into which he could not introduce his whole body.

Although queen cells (Fig. I, F, G, H) are of a different shape and very much thicker, yet the excavating instinct is brought to bear upon them too. Circular, pits are scooped out, and as Waterhouse (167) has shown, where two of these meet they assume a straight line between them.

Wax, when pure, is pale yellow, but sometimes nearly white, and the colouring is due, as Dr. Planta (130) has pointed out, to pollen consumed by the bees. For instance, when bees are collecting pollen and honey from heather, the pollen being white, the wax is also white; whereas, when collecting from sainfoin, the pollen being orange-coloured, the wax also partakes of this colour.

According to Brande, wax is composed of 80·20 per cent carbon, 13·14 hydrogen, and 6·36 oxygen, but during the process of bleaching it parts with one per cent of carbon and absorbs one per cent of oxygen.

Its specific gravity is between ·960 and ·965, and it melts between 145° and 150° Fahr. At 85° it becomes plastic, and is then readily moulded and kneaded into shape. Bees, besides making wax in the way we have described, will use up any wax they may find handy, and that from discarded queen cells is generally so used. Any impurities contained in such wax are incorporated in the walls.

The coverings of honey cells are usually made of wax, but those of brood cells have pollen added to make the caps porous; and for the same reason the walls of queen cells have also pollen in them. The cappings of drone brood are much more convex

than those of worker brood, and the domes are braced to each other by wax girders.

And now that our task is ended, if the reader has carefully followed us, he will be impressed by the wonderful economy of the hive. Wherever we investigate the wonderful works of Nature we find the most beautiful adaptation and arrangement in correlation of structure and function. Nor have we seen it to be otherwise with bees. We have learned that there are three different sorts of bees composing a hive: a *queen*, the mother of the hive; numerous *workers*, or undeveloped females; and *drones*, or males. In speaking of the queen as the 'mother,' we have borrowed a German expression, and a most suitable one it is, for she deposits the eggs from which (in a normal state) all the inhabitants of the hive proceed. These eggs, all alike in appearance, laid in different cells produce males or females according to the size of the cell, and in consequence of a wonderful mechanical adaptation are fertilised or not, apparently at the will of the queen, and it is one of the mysteries of the hive how a queen knows where and when to deposit each particular kind of egg. Just as in various stages of infancy, the human being requires and receives a modification of his food, so we find the larvæ of bees are treated by the nurses much after the same fashion. The division of labour, is another of those adaptations which deserve our admiration, and we cannot but be struck by the complexity and wonderful perfection in structure of the various organs adapted to their

different uses in the several sorts of bees. Each bee is adapted to its special work, which it performs independently of the others, but for the common good. What infinite wisdom has been displayed in the creation of these little creatures, far surpassing man's understanding! In the most exquisite works of man, the microscope only reveals imperfections, and the higher the power used the more imperfect do they appear; but in those of Nature, we find the higher powers only bring out more wonderful and complex structures of infinite perfection. Much has been done during the present century with improved microscopes and greater knowledge, but there still remains much to be done. We have described several organs, the uses of which are not yet known, and even with regard to others, such as those connected with the senses of seeing, smelling, and hearing, much remains to be proved.

We shall be contented if those who read this book are induced by its perusal to take a deeper interest in the works of Nature, and they will be convinced that, much as we know already, there is still more to learn; and we are sure that a careful investigation by those who are able to devote some time to it, will well reward them, and cannot fail to lead to discoveries on the part of the student that will help to elucidate some of those points at present enveloped in mystery.

An intimate knowledge of the anatomy and physiology of bees cannot but be useful to us in practical management, and must give us greater interest in the culture and observation of these creatures.

And now we cannot do better than conclude by quoting the words of Lord Brougham, who says:

'We are raised by science to an understanding of the infinite wisdom and goodness which the Creator has displayed in all His works. Not a step can we take in any direction without perceiving the most extraordinary traces of design; and the skill everywhere conspicuous is calculated in so vast a proportion of instances to promote the happiness of living creatures, and especially ourselves, that we feel no hesitation in concluding that if we knew the whole scheme of Providence, every part would appear to be in harmony with a plan of absolute benevolence. Independently, however, of this most consoling inference, the delight is inexpressible of being able to follow the marvellous works of the Great Author of Nature, and to trace the unbounded power and exquisite skill which are exhibited by the most minute as well as the mightiest parts of His system.'

DESCRIPTION OF ILLUSTRATIONS.

√*Frontispiece.*—Section of bee, showing internal organs.—*a*, brain; *b*, *c*, *d*, ganglia; *e*, compound eye; *f*, œsophagus; *g*, honey stomach; *h*, stomach mouth; *i*, chyle stomach; *k*, small intestine; *l*, malpighian tubes; *m*, large intestine; *n*, rectal glands; *o*, anal opening; *p*, poison sac; *r*, sting; *s*, spiracle; *t*, air sacs; *u*, lubricating gland.

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